DCE-12

3 February 1997

Data Report

Dielectric Properties of Soils

Fort A. P. Hill, VA -- 2nd Sample Set

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Clifton, Peggy

From: George, Vivian Ms PM-MCD [vivian.george@nvl.army.mil]
Sent: Friday, April 27, 2001 9:27 AM
To: 'Clifton, Peggy'
Subject: RE: Distribution on DARPA/Walcoff Documents & Data

All are approved for public distribution A, unlimited.

-----Original Message-----
From: Clifton, Peggy [mailto:pclifton@dtic.mil]
Sent: Wednesday, April 11, 2001 9:50 AM
To: 'Vivian George'
Subject: Distribution on DARPA/Walcoff Documents & Data

Vivian,

I am putting in the background clutter data documents and discs; some are marked "Approved for public release, distribution is unlimited," but others have no markings for distribution. Are they all unlimited distribution? If, not we will have to figure out what the distribution levels are for the unmarked documents. TIA,

Peg Clifton

Margaret Clifton
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"Civilization advances by extending the number
of important operations which we can perform without thinking about them."
-Alfred North Whitehead

Introduction

This report contains dielectric property measurement results for soils. The original data were collected in the form of the real and imaginary parts of the complex dielectric constant versus frequency utilizing a Hewlett-Packard 8510C Vector Network Analyzer System with an S-Parameter Test Set and a coaxial sample holder. Software developed at the U.S. Army Engineer Waterways Experiment Station was used to convert S-parameter measurements at selected frequencies into a complex dielectric constant. The soils were assumed to be nonmagnetic. Other useful electromagnetic properties were calculated from the dielectric constant and frequency, including an equivalent electrical conductivity, the loss tangent, power attenuation, and a normalized phase velocity. The section entitled, "Fundamental Relationships," contains the formulae used to calculate these properties. Additional physical parameters of the soil samples that are included in the report include their dry density, volumetric moisture content, and temperature.

Measurement results and calculated parameters are listed at four selected frequencies and displayed as a function of volumetric moisture content. The intent of presenting data in this way is to demonstrate the experimental observation that the real part of the dielectric constant, as well as the normalized phase velocity are strong functions of volumetric moisture and reasonably independent of soil texture. Other parameters are clearly dependent on soil texture, and, given enough data from several different types of soils, their graphs versus moisture content would show a great deal of scatter. The four frequencies chosen for data presentation span the range of frequencies normally associated with ground penetrating radars.

For additional details on how the data were collected, please contact the first author at the U.S. Army Engineer Waterways Experiment Station (WES), Vicksburg, MS, (voice: 601-634-2855, FAX: 601-634-2732, e-mail: curtisj@ex1.wes.army.mil).

Source of Soil Samples

The samples used for these measurements were collected in the last week of August, 1996, by Messrs. Chuck Hahn, David Leese, and Joe Wooley, all members of the site investigation team from WES. Bag samples of soil were taken from five different locations on each test site at Fort A.P. Hill. At each of these five locations a near-surface sample was acquired along with a sample at a depth of about 0.5 meters and another at a depth of about 1.0 meter.

The two test sites at Fort A.P. Hill were located at Firing Point 20 and Firing Point 22. Each individual soil sample has been given unique identifiers making use of the site name, the easting coordinate, in meters (relative to the southwest corner of the test site), where the sample was collected, and the depth from which it was taken. The character "1" was used for samples taken from a depth of one meter; a "2" was assigned to those collected at one-half of a meter; and an "s" identifies surface samples. One additional character was added to the sample identifier to indicate whether the soil used came straight from the sample bag in an "as is" condition (the letter "b"), or had been air dried while still in the sample holder (the letter "d"), or, finally, had been wetted with distilled deionized water while still in the sample holder (the letter "w"). Using these guidelines, the sample identifier , 20123_2d, refers to a sample collected from the Firing Point 20 test site at a location 123 meters east and 97 meters north of the southwest corner, at a depth of 0.5 meters, and which had been air-dried prior to measurement of its electrical properties.

Experimental Procedures

The experimental procedure used to collect electrical property data at WES normally consists of the following steps. First of all, soil is taken from the source container and packed into a brass coaxial sample holder using small spoons and other utensils. The holders used in these measurements have a square cross section whose dimension is 0.75 cm and are either 5 cm or 10 cm in length, resulting in total sample volumes of about 2.8 cm^3 and 5.6 cm^3, respectively. The samples are packed as tightly as possible at whatever moisture content they retained in the bags. Hence, there is no control over sample dry density. It is highly unlikely, however, that the densities achieved by this sample preparation technique will ever exceed ***in situ*** densities.

After enclosing the sample in the holder with a brass cover plate, the holder is placed in a temperature control device and connected to the S-parameter test set. After the sample has reached the desired temperature, data are collected over the selected range of frequencies. Following removal of the sample holder from the temperature control apparatus, the cover plate is removed, and the sample is allowed to air dry (usually for a twenty-four hour period). After the collected of a second set of data at nominally-dry conditions, the sample is wetted to near saturation by the careful addition of distilled, deionized water. After allowing some time for the added moisture to fully penetrate the soil structure (usually about an hour), the electrical properties are once again measured. Therefore, each sample is tested three times, once as is, once after air drying, and once at near-saturation conditions. The addition of water would not work for a sample that contained a large amount of swelling clay minerals, as the sample would expand too far out of the sample holder to allow a measurement to be made.

Sample masses are recorded prior to each measurement. Following the last data collection, the soil is scraped and flushed from the sample holder and dried in an oven to obtain its dry mass, which, by virtue of knowing the sample volume, leads to the sample dry density and the calculation of sample volumetric moisture contents for each measurement. Of course, these data can also be used to calculate the commonly used weight-based moisture content as well.

Fundamental Relationships

Assuming plane harmonic wave propagation in a lossy, non-magnetic, unbounded medium, the wave amplitude function may be written:

$$e^{i(kx - \omega t)}$$

where

k	$= \beta + i\alpha \qquad = \omega N/c$	
	is the complex propagation constant,	
β	is the phase constant,	
α	is the amplitude attenuation factor,	
ω	is the radial frequency,	
N	is the complex index of refraction,	
c	is the velocity of light in a vacuum,	
i	is the symbol designating an imaginary quantity = $\sqrt{-1}$,	
x	is a space coordinate, and	
t	is time.	

Furthermore,

$$N^2 = \epsilon = \epsilon' + \epsilon''$$

where ϵ is the relative complex dielectric constant, which, along with the electrical conductivity from Ohm's Law, represents the electrical properties of the medium. The interpretation of these properties as used in this study is that the conductivity, σ , accounts for current due to free charged particle motion, while the imaginary part of the complex dielectric constant, ϵ'' , accounts for displacement current losses (those due to the electric polarization of the medium). When both conduction and displacement currents are considered, one finds two terms in Ampere's law for current flow that represent losses (or a shift in phase), one containing the electrical conductivity and one containing the imaginary part of the dielectric constant. While these two terms account

for different loss mechanisms, most researchers use only one term or the other to identify losses, with many users preferring to deal with the concept of electrical conductivity. In MKS units, the relationship between the two quantities is taken to be

$$\sigma = \epsilon'' \epsilon_0 \omega$$

where the units of conductivity are mhos/meter (or siemens/meter) and ϵ_0 is the permittivity of free space (8.85×10^{-12} farads/meter).

Squaring the expression for the complex propagation constant, substituting the expression for the square of the complex index of refraction, and equating real and imaginary components, one obtains two algebraic equations that relate the amplitude attenuation factor and phase constant to the complex dielectric constant:

$$\beta^2 - \alpha^2 = \frac{\omega^2}{c^2}\epsilon'$$

and

$$\alpha\beta = \frac{\omega^2 \epsilon''}{2c^2}$$

Solving these equations for the amplitude attenuation factor and for the phase constant results in the following expressions:

$$\alpha = \frac{\omega}{c}\left(\frac{\epsilon'}{2}\left(\sqrt{1 + \left(\frac{\epsilon''}{\epsilon'}\right)^2} - 1\right)\right)^{1/2}$$

and

$$\beta = \frac{\omega}{c}\left(\frac{\epsilon'}{2}\left(\sqrt{1 + \left(\frac{\epsilon''}{\epsilon'}\right)^2} + 1\right)\right)^{1/2}$$

The ϵ''/ϵ' ratio is also referred to as the loss tangent. Some researchers prefer to work with the electrical conductivity in place of the dielectric loss term.

Plane waves of constant phase will propagate with a velocity

$$v = \frac{\omega}{\beta} = c\left(\frac{\epsilon'}{2}\left(\sqrt{1 + \left(\frac{\epsilon''}{\epsilon'}\right)^2} + 1\right)\right)^{-1/2}$$

This phase velocity is not necessarily the speed with which the energy of the wave propagates through the

medium. The latter is refered to as the group velocity and can be calculated as the rate of change of radial frequency with respect to the phase constant. However, as long as the phase velocity is relatively constant over the range of frequencies of interest, then there is little difference between phase velocity and group velocity.

The power intensity of the plane electromagnetic wave decreases exponentially with depth of penetration by the factor, $e^{-2\alpha x}$, or, in one unit of distance traveled, a decrease of $e^{-2\alpha}$. Power attenuation expressed in decibels per meter can then be written as:

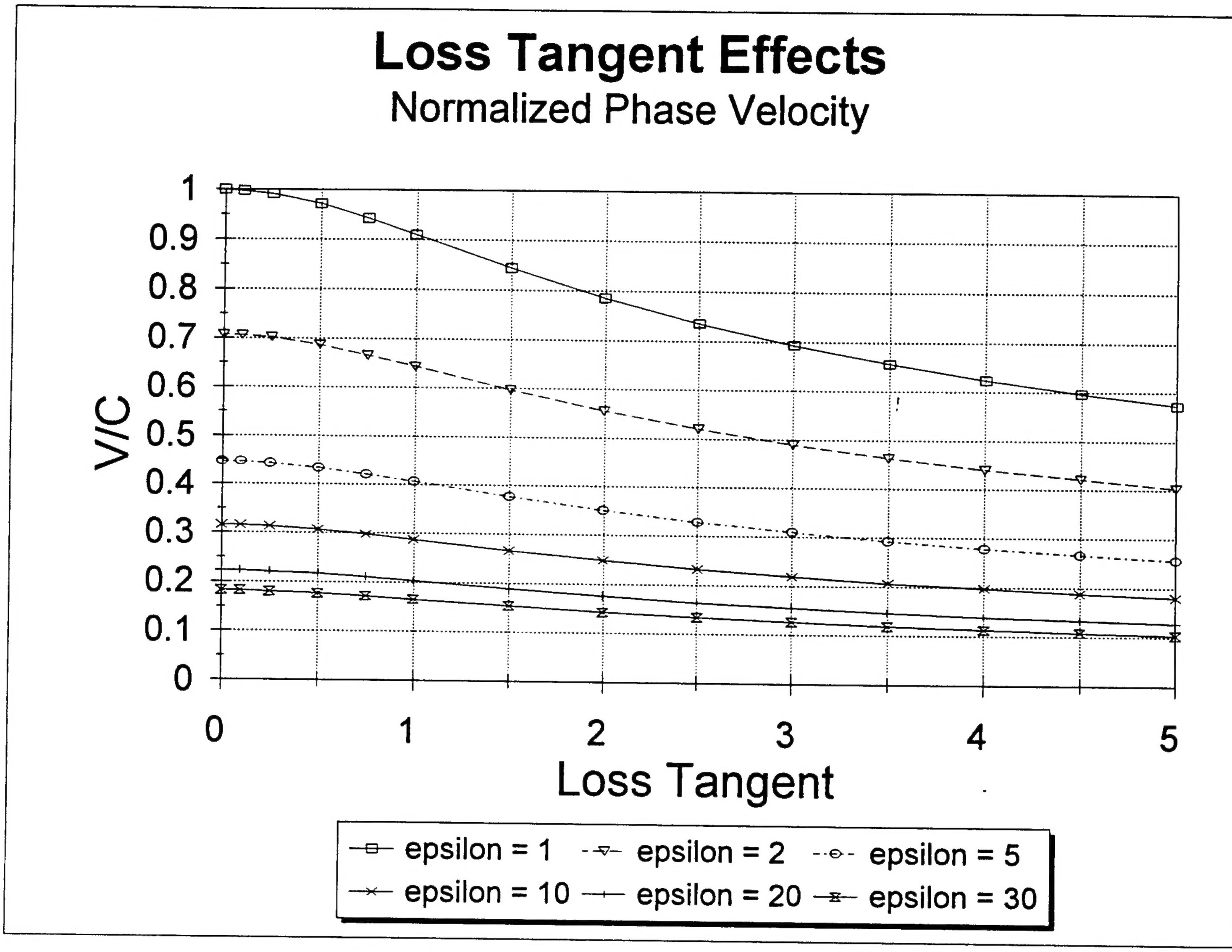
$$PL = -8.6859 \frac{\omega}{c} \left(\frac{\epsilon'}{2} \left(\sqrt{1 + \left(\frac{\epsilon''}{\epsilon'} \right)^2} - 1 \right) \right)^{1/2}$$

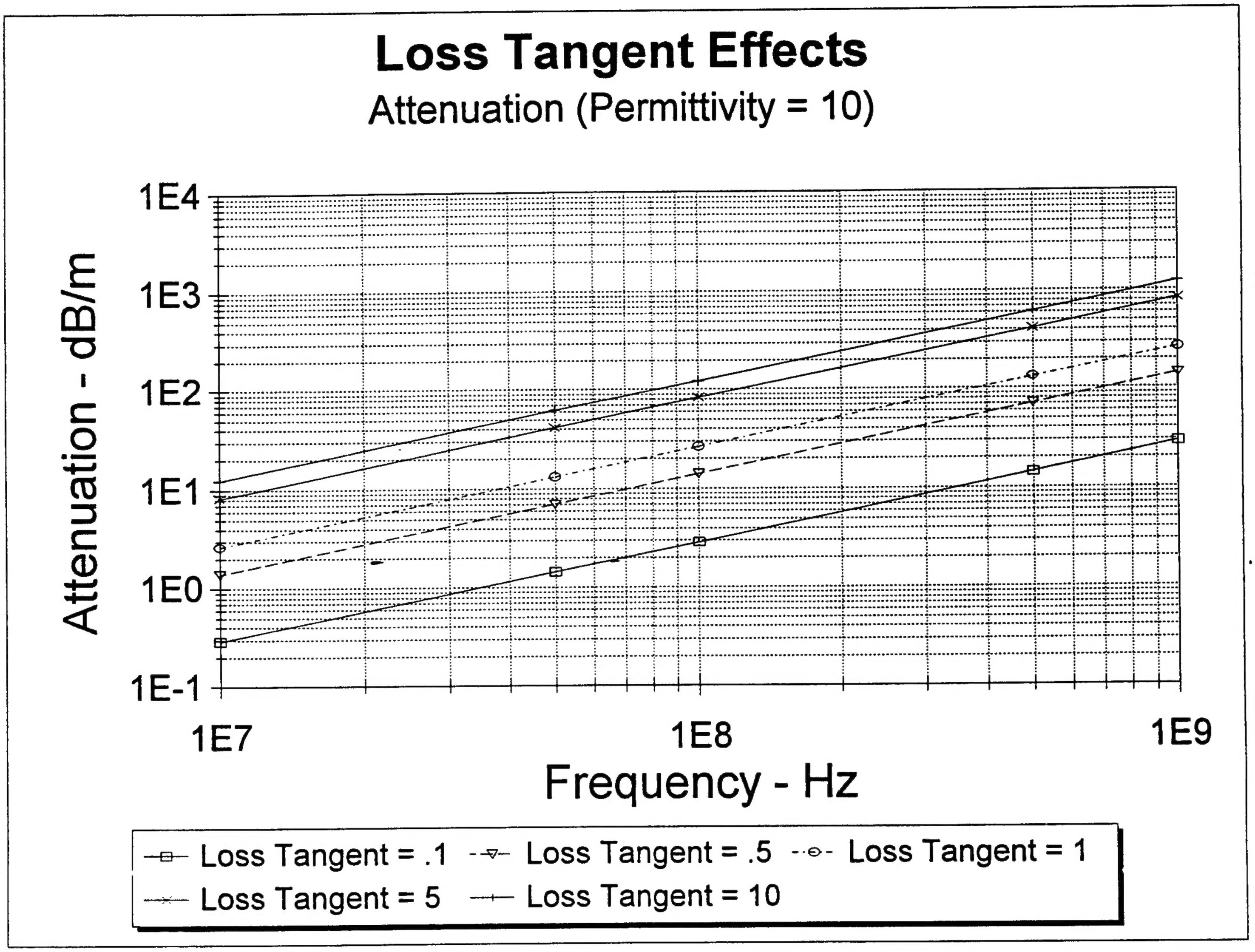
Theoretical Loss Tangent Effects

The most straightforward design of a ground-penetrating radar data collection effort and subsequent analysis of those data would require estimates of the speed with which a radar signal will propagate through the terrain and the rate at which the power level of the signal will be attenuated. The former provides the locations of subsurface anomalies, while the latter controls the depth to which meaningful data can be collected.

Usually, phase velocity is taken to be a good approximation of electromagnetic wave speed. Furthermore, many designers and analysts choose to assume that the material through which the wave is propagating is relatively lossless. The first figure that follows is a plot of normalized phase velocity (v/c) for selected values of the real part of the complex dielectric constant (often referred to as the permittivity of the material) against values of the loss tangent. The permittivity values easily span the range of values found in most soils. The figure clearly demonstrates that as long as the loss tangent is relatively small (say, less than 0.5), the lossless material assumption is a good one. However, a loss tangent of 1.0, which is not uncommon, will result in about a ten percent error in phase velocity compared to the lossless assumption.

As for signal power attenuation, obviously the lossless material assumption is meaningless. One can see from the second plot that follows that the rate at which the power level of an electromagnetic wave decreases when traveling through the soil is very sensitive to the value of the loss tangent and to the frequency at which the signal is being propagated.


Loss Tangent Effects
Normalized Phase Velocity
V/C
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
1
2
3
4
5
Loss Tangent
epsilon = 1
epsilon = 2
epsilon = 5
epsilon = 10
epsilon = 20
epsilon = 30



Loss Tangent Effects
Attenuation (Permittivity = 10)
1E4
1E3
1E2
1E1
1E0
1E-1
Attenuation - dB/m
1E7
1E8
1E9
Frequency - Hz
Loss Tangent = .1
Loss Tangent = .5
Loss Tangent = 1
Loss Tangent = 5
Loss Tangent = 10

Representative Data

The following pages contain a sample of the electrical property data associated with these Fort A.P. Hill soil samples. Although laboratory data are collected as a function of frequency for a constant value of volumetric moisture, it has been found that one particularly useful format for displaying these data is to plot results (both measured and calculated) versus moisture content at selected frequencies. The frequencies chosen for this report are 50, 100, 200, and 895 MHz, and were chosen to be representative of the normal operating frequencies of ground penetrating radar systems.

At each frequency, the data are presented in the following way. First of all, one will find a table of measured and calculated parameters, the first page being for samples taken from Firing Point 20, and the second page being for Firing Point 22 samples. The first column of each page provides the location and depth code, while the second column lists the volumetric moisture content (in percent) of that particular sample. The third column contains the dry density (in grams per cubic centimeters) of the sample that was tested. The last six columns list the real and imaginary components of the measured relative complex dielectric constant, the equivalent conductivity (in mhos per meter), the loss tangent, the power attenuation factor in decibels per meter, and the normalized phase velocity.

The table is followed by several plots of parameters versus volumetric moisture. The first six plots represent a composite of all sample depths and both test sites. Experience from previous data collection efforts with many different types of soils has shown that the permittivity and the normalized phase velocity are very strong functions of volumetric moisture and virtually independent of soil type. These data confirm those previous observations. The first six plots clearly establish that <u>there is no fundamental difference in electrical property values for the two test sites</u>.

The next question to be answered is whether or not sample depth makes a difference in electrical properties. This question is addressed by plotting the six parameters versus moisture content while distinguishing sample depth. Six plots appear for the Firing Point 20, and six plots are shown for the Firing Point 22 soils. Once again, the overwhelming conclusion is that <u>there is no difference in electrical properties as a result of sample depth</u>.

Fort A.P. Hill_2
Properties at 50 Mhz

Fort AP Hill_2 Soil Properties at 50 MHz

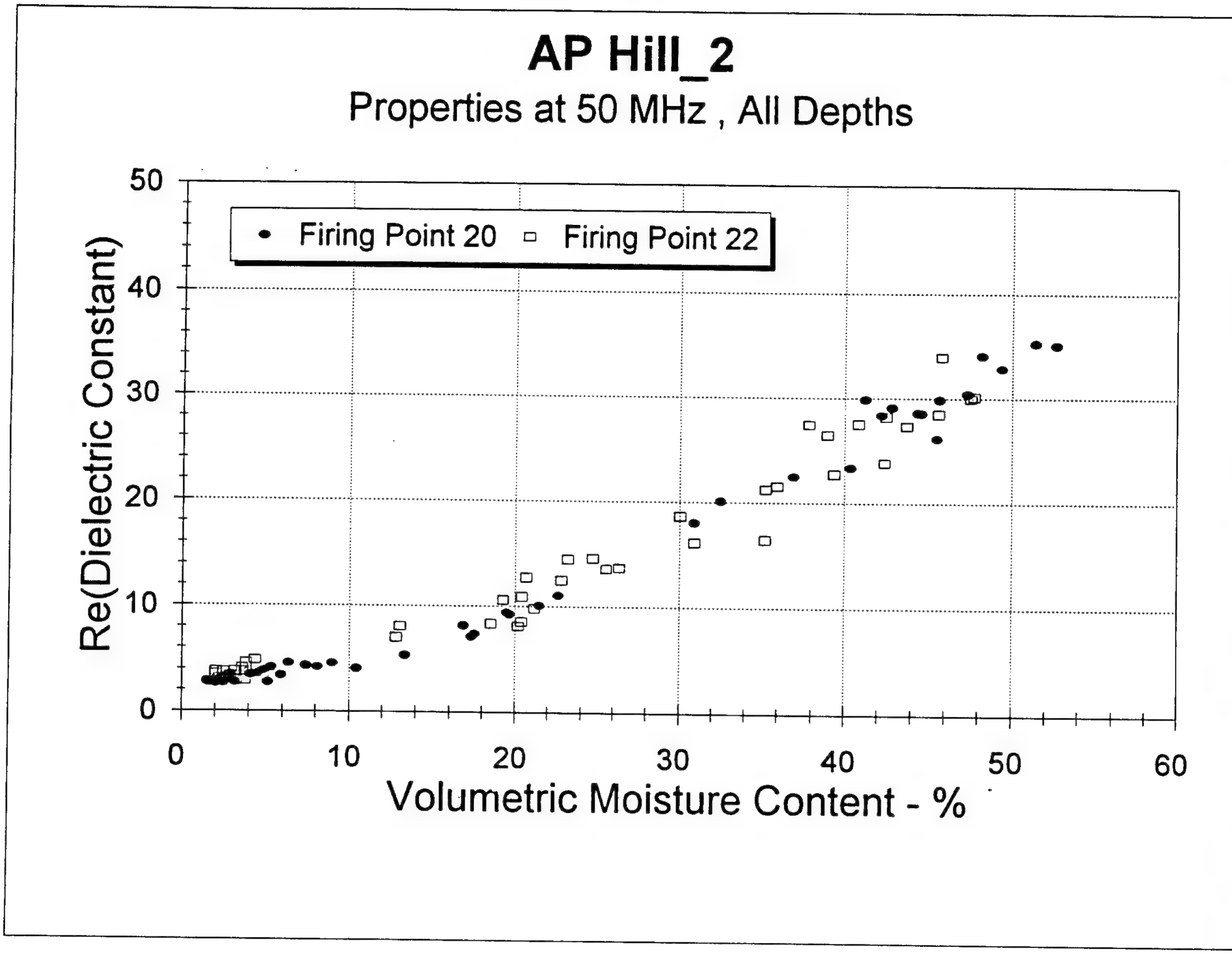
Firing Point 20

File Name	Vol Moist	Dry Dens g/cc	Re(eps)	Im(eps)	Cond mho/m	Loss Tan	Attn dB/m	Norm Vel
200_1b	2.57	1.40	3.22	0.33	0.001	0.10	0.84	0.56
200_1d	2.65	1.40	3.25	0.39	0.001	0.12	0.98	0.55
200_1w	49.42	1.40	32.93	6.00	0.017	0.18	4.74	0.17
200_2b	5.97	1.21	3.41	0.47	0.001	0.14	1.16	0.54
200_2d	2.52	1.21	2.69	0.23	0.001	0.08	0.62	0.61
200_2w	51.44	1.21	35.35	4.84	0.014	0.14	3.69	0.17
200_sb	9.01	1.39	4.54	0.55	0.002	0.12	1.17	0.47
200_sd	2.27	1.39	2.92	0.18	0.001	0.06	0.47	0.58
200_sw	47.36	1.39	30.48	3.23	0.009	0.11	2.66	0.18
20122_1b	30.94	1.53	18.03	11.83	0.033	0.66	12.09	0.22
20122_1d	6.41	1.53	4.54	1.35	0.004	0.30	2.85	0.46
20122_1w	41.25	1.53	29.91	16.37	0.046	0.55	13.16	0.18
20122_2b	16.89	1.37	8.20	3.10	0.009	0.38	4.84	0.34
20122_2d	2.98	1.37	3.47	0.47	0.001	0.14	1.15	0.54
20122_2w	48.22	1.37	34.13	10.68	0.030	0.31	8.22	0.17
20122_sb	17.37	1.47	7.14	3.12	0.009	0.44	5.19	0.37
20122_sd	3.19	1.47	2.73	0.14	0.000	0.05	0.37	0.61
20122_sw	40.39	1.47	23.34	7.93	0.022	0.34	7.36	0.20
20123_1b	8.11	1.33	4.21	0.81	0.002	0.19	1.78	0.49
20123_1d	1.61	1.33	2.74	0.18	0.001	0.06	0.49	0.60
20123_1w	52.69	1.33	35.15	5.25	0.015	0.15	4.02	0.17
20123_2b	21.49	1.66	10.13	3.84	0.011	0.38	5.40	0.31
20123_2d	4.55	1.66	3.52	0.56	0.002	0.16	1.36	0.53
20123_2w	32.55	1.66	20.12	6.56	0.018	0.33	6.56	0.22
20123_sb	19.71	1.54	9.26	5.28	0.015	0.57	7.60	0.32
20123_sd	1.95	1.54	2.87	0.10	0.000	0.03	0.26	0.59
20123_sw	36.96	1.54	22.48	12.99	0.036	0.58	12.01	0.20
2027_1b	7.44	1.53	4.33	0.47	0.001	0.11	1.03	0.48
2027_1d	1.54	1.53	2.78	0.05	0.000	0.02	0.15	0.60
2027_1w	44.38	1.53	28.61	2.08	0.006	0.07	1.77	0.19
2027_2b	22.63	1.53	11.08	4.21	0.012	0.38	5.65	0.30
2027_2d	5.34	1.53	4.11	0.92	0.003	0.22	2.06	0.49
2027_2w	42.86	1.53	29.13	9.91	0.028	0.34	8.24	0.18
2027_sb	10.49	1.44	4.04	0.38	0.001	0.09	0.86	0.50
2027_sd	5.16	1.44	2.73	0.07	0.000	0.03	0.19	0.61
2027_sw	45.55	1.44	26.16	3.23	0.009	0.12	2.87	0.20
2065_1b	17.55	1.47	7.40	1.99	0.006	0.27	3.30	0.36
2065_1d	4.15	1.47	3.43	0.52	0.001	0.15	1.26	0.54
2065_1w	44.58	1.47	28.58	6.43	0.018	0.22	5.44	0.19
2065_2b	19.52	1.48	9.44	2.97	0.008	0.31	4.34	0.32
2065_2d	4.91	1.48	3.84	0.68	0.002	0.18	1.58	0.51
2065_2w	42.22	1.48	28.39	7.30	0.020	0.26	6.18	0.19
2065_sb	13.39	1.37	5.32	0.69	0.002	0.13	1.36	0.43
2065_sd	2.09	1.37	2.62	0.14	0.000	0.05	0.40	0.62
2065_sw	45.70	1.37	29.89	4.02	0.011	0.13	3.34	0.18

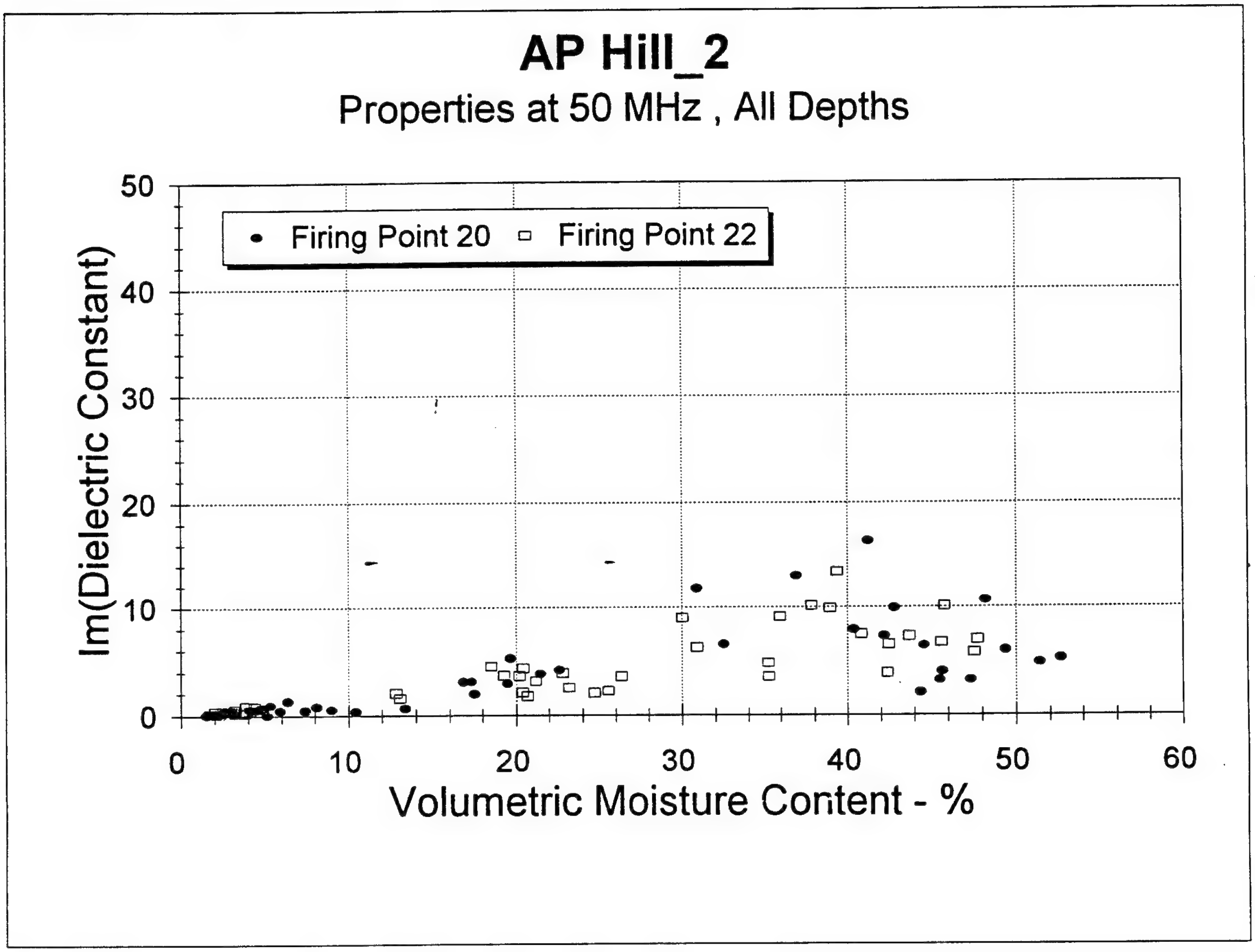
Fort AP Hill_2 Soil Properties at 50 MHz

Firing Point 22

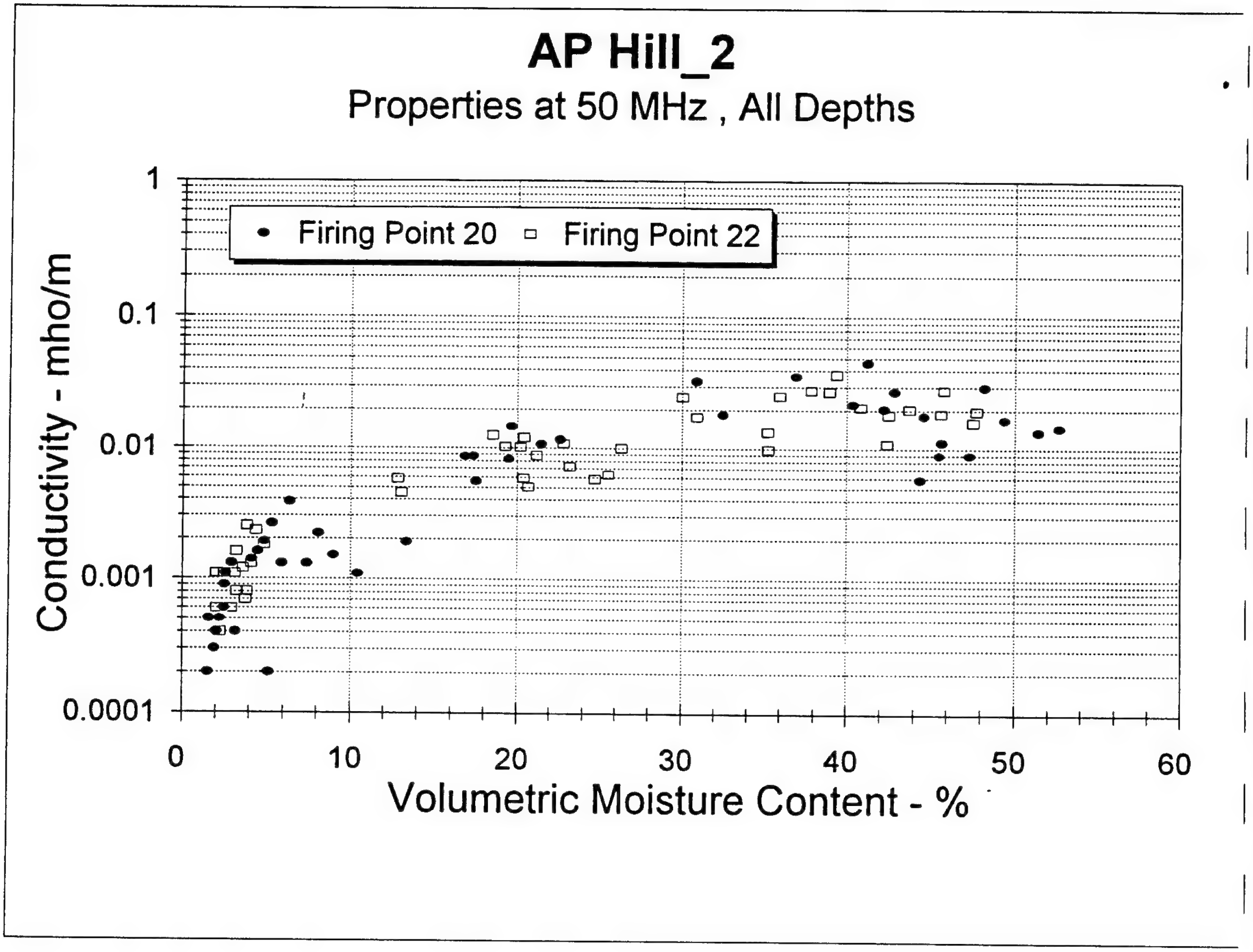
File Name	Vol Moist	Dry Dens g/cc	Re(eps)	Im(eps)	Cond mho/m	Loss Tan	Attn dB/m	Norm Vel
22122_1b	19.30	1.53	10.63	3.72	0.010	0.35	5.11	0.30
22122_1d	3.88	1.53	4.59	0.88	0.003	0.19	1.87	0.46
22122_1w	45.79	1.53	34.02	10.15	0.028	0.30	7.83	0.17
22122_2b	20.45	1.83	10.95	4.34	0.012	0.40	5.86	0.30
22122_2d	2.94	1.83	3.37	0.23	0.001	0.07	0.57	0.54
22122_2w	35.24	1.83	16.46	4.84	0.014	0.29	5.37	0.24
22122_sb	13.05	1.69	8.08	1.62	0.005	0.20	2.58	0.35
22122_sd	2.04	1.69	3.54	0.39	0.001	0.11	0.93	0.53
22122_sw	35.25	1.69	21.26	3.57	0.010	0.17	3.51	0.22
22123_1b	21.20	1.53	9.83	3.17	0.009	0.32	4.54	0.32
22123_1d	4.87	1.53	3.67	0.65	0.002	0.18	1.54	0.52
22123_1w	43.69	1.53	27.37	7.30	0.020	0.27	6.29	0.19
22123_2b	12.82	1.51	7.06	2.08	0.006	0.30	3.53	0.37
22123_2d	3.22	1.51	3.73	0.58	0.002	0.16	1.36	0.52
22123_2w	45.59	1.51	28.53	6.72	0.019	0.24	5.68	0.19
22123_sb	18.55	1.55	8.38	4.52	0.013	0.54	6.87	0.33
22123_sd	3.80	1.55	2.98	0.25	0.001	0.08	0.66	0.58
22123_sw	39.36	1.55	22.72	13.42	0.037	0.59	12.31	0.20
2227_1b	26.33	1.51	13.70	3.61	0.010	0.26	4.40	0.27
2227_1d	3.15	1.51	3.80	0.40	0.001	0.11	0.93	0.51
2227_1w	42.47	1.51	28.28	6.54	0.018	0.23	5.56	0.19
2227_2b	37.85	1.66	27.50	10.19	0.028	0.37	8.70	0.19
2227_2d	4.37	1.66	4.83	0.83	0.002	0.17	1.71	0.45
2227_2w	38.96	1.66	26.50	9.92	0.028	0.37	8.62	0.19
2227_sb	47.54	1.31	30.03	5.80	0.016	0.19	4.79	0.18
2227_sd	2.27	1.31	3.11	0.13	0.000	0.04	0.35	0.57
2227_sw	42.39	1.31	23.85	3.94	0.011	0.17	3.66	0.20
222_1b	20.41	1.40	8.57	2.11	0.006	0.25	3.25	0.34
222_1d	4.12	1.40	3.63	0.47	0.001	0.13	1.13	0.52
222_1w	47.74	1.40	30.21	6.99	0.019	0.23	5.75	0.18
222_2b	22.82	1.57	12.53	3.92	0.011	0.31	4.98	0.28
222_2d	2.51	1.57	3.71	0.41	0.001	0.11	0.97	0.52
222_2w	40.82	1.57	27.55	7.51	0.021	0.27	6.45	0.19
222_sb	20.23	1.55	8.16	3.68	0.010	0.45	5.72	0.34
222_sd	3.26	1.55	2.86	0.28	0.001	0.10	0.74	0.59
222_sw	35.92	1.55	21.54	9.13	0.025	0.42	8.76	0.21
2265_1b	23.21	1.99	14.52	2.57	0.007	0.18	3.06	0.26
2265_1d	3.65	1.99	4.06	0.44	0.001	0.11	0.98	0.50
2265_1w	25.57	1.99	13.62	2.25	0.006	0.17	2.76	0.27
2265_2b	20.71	1.94	12.80	1.79	0.005	0.14	2.28	0.28
2265_2d	2.09	1.94	3.76	0.20	0.001	0.05	0.47	0.52
2265_2w	24.72	1.94	14.56	2.08	0.006	0.14	2.47	0.26
2265_sb	30.08	1.82	18.65	9.04	0.025	0.48	9.27	0.23
2265_sd	3.87	1.82	3.81	0.28	0.001	0.07	0.65	0.51
2265_sw	30.94	1.82	16.15	6.31	0.018	0.39	7.01	0.24

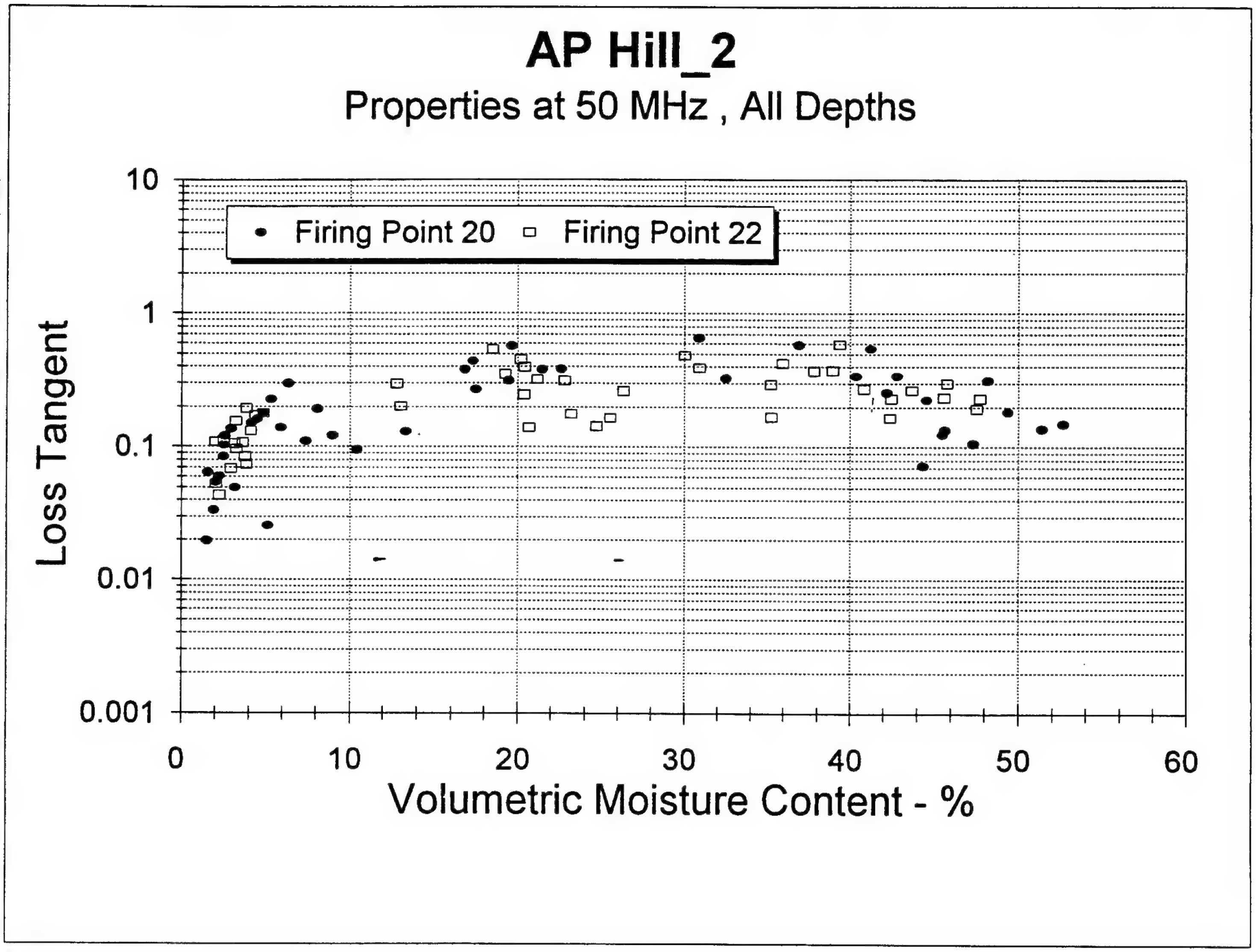


AP Hill_2
Properties at 50 MHz , All Depths
Firing Point 20
Firing Point 22
Re(Dielectric Constant)
0
10
20
30
40
50
0
10
20
30
40
50
60
Volumetric Moisture Content - %

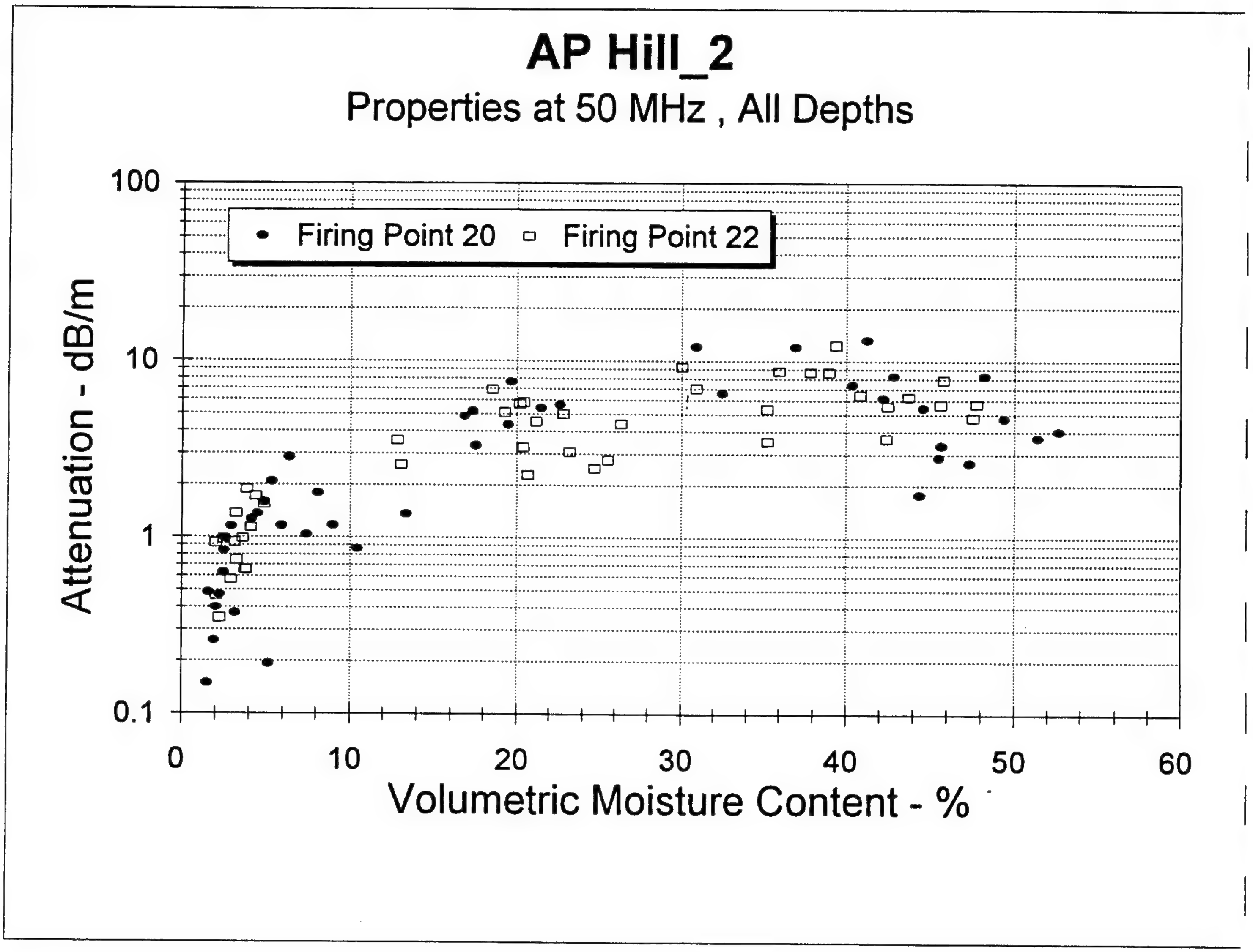


AP Hill_2
Properties at 50 MHz , All Depths
Firing Point 20
Firing Point 22
Im(Dielectric Constant)
Volumetric Moisture Content - %
0
10
20
30
40
50
60

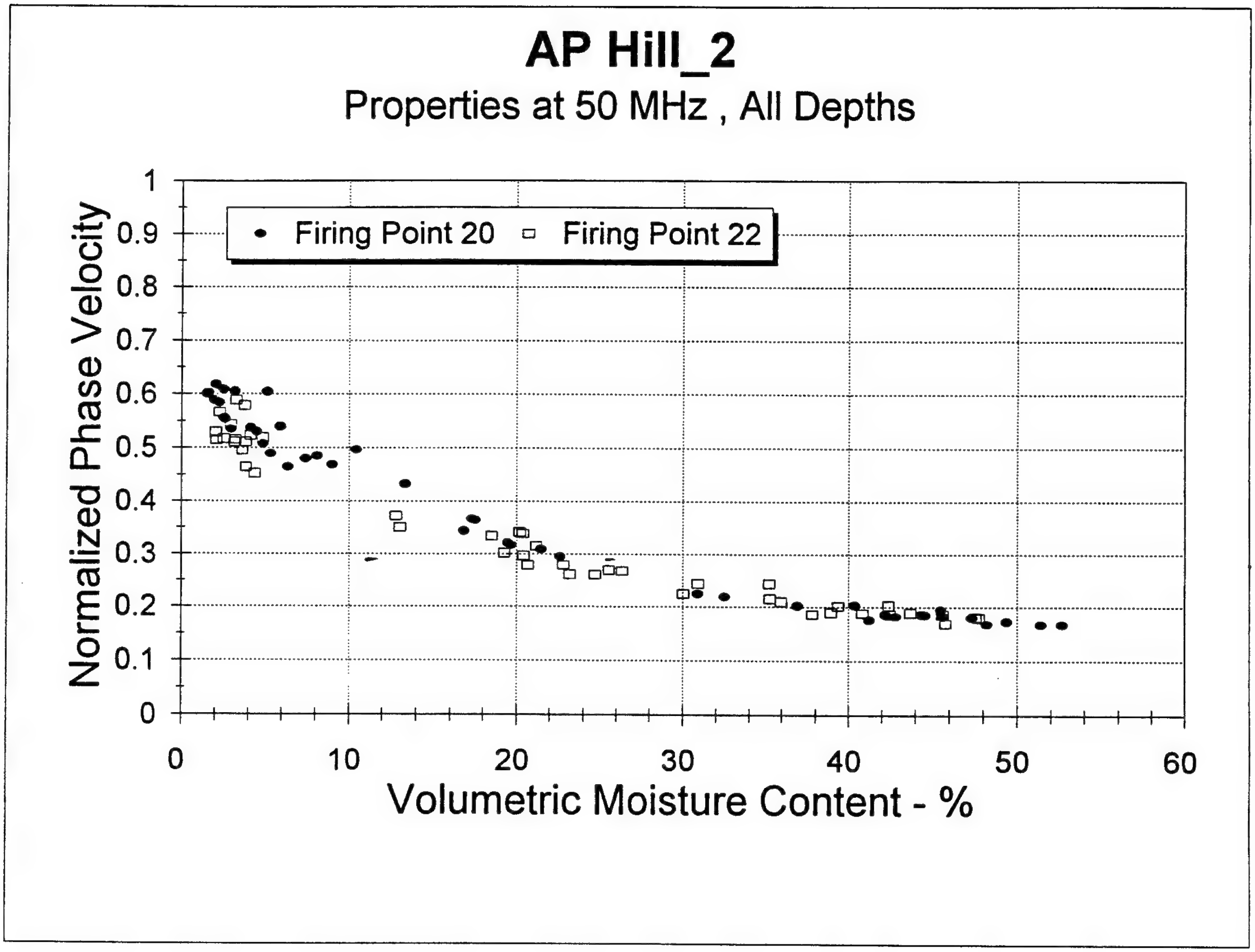

AP Hill_2
Properties at 50 MHz , All Depths
Firing Point 20
Firing Point 22
Conductivity - mho/m
1
0.1
0.01
0.001
0.0001
0
10
20
30
40
50
60
Volumetric Moisture Content - %

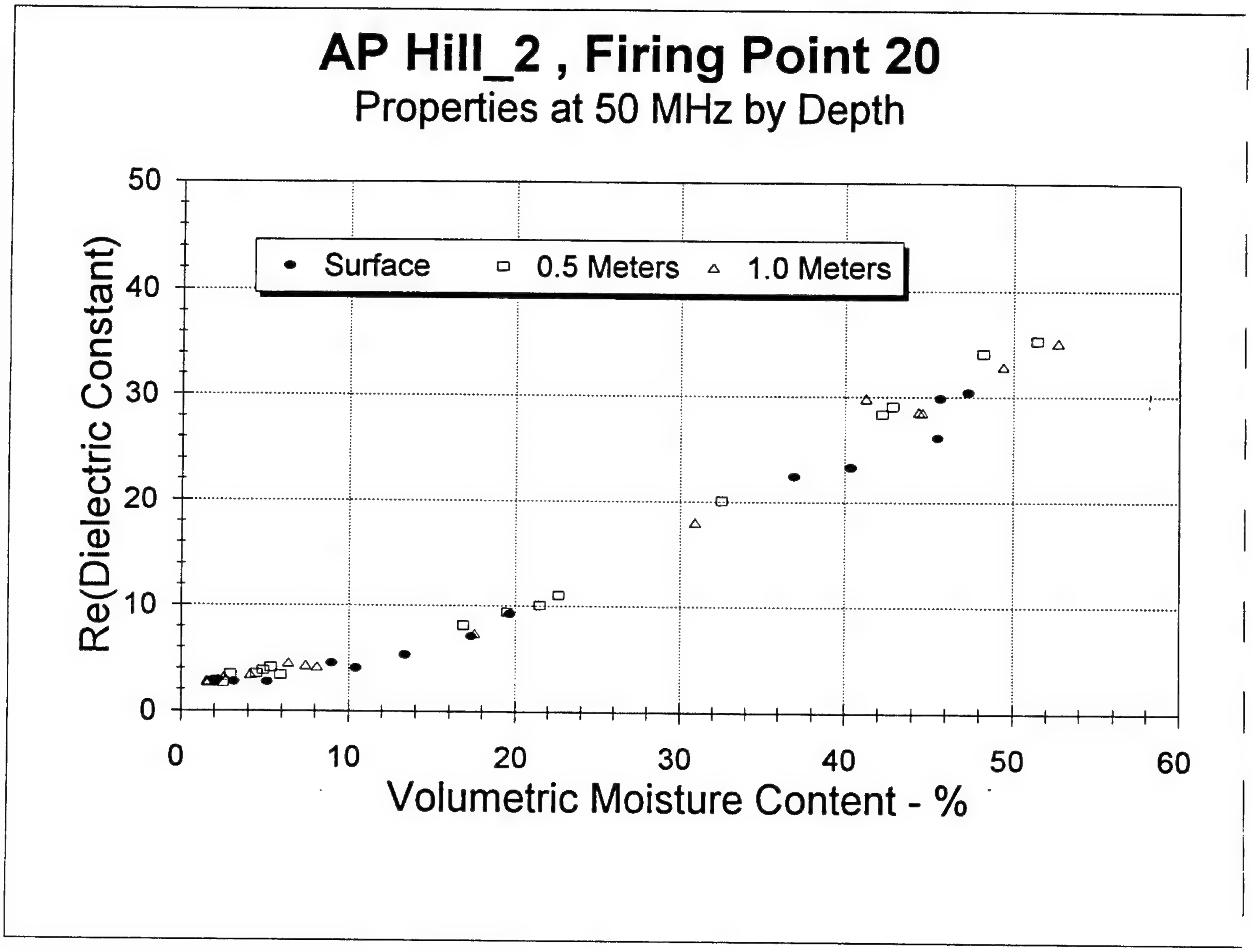


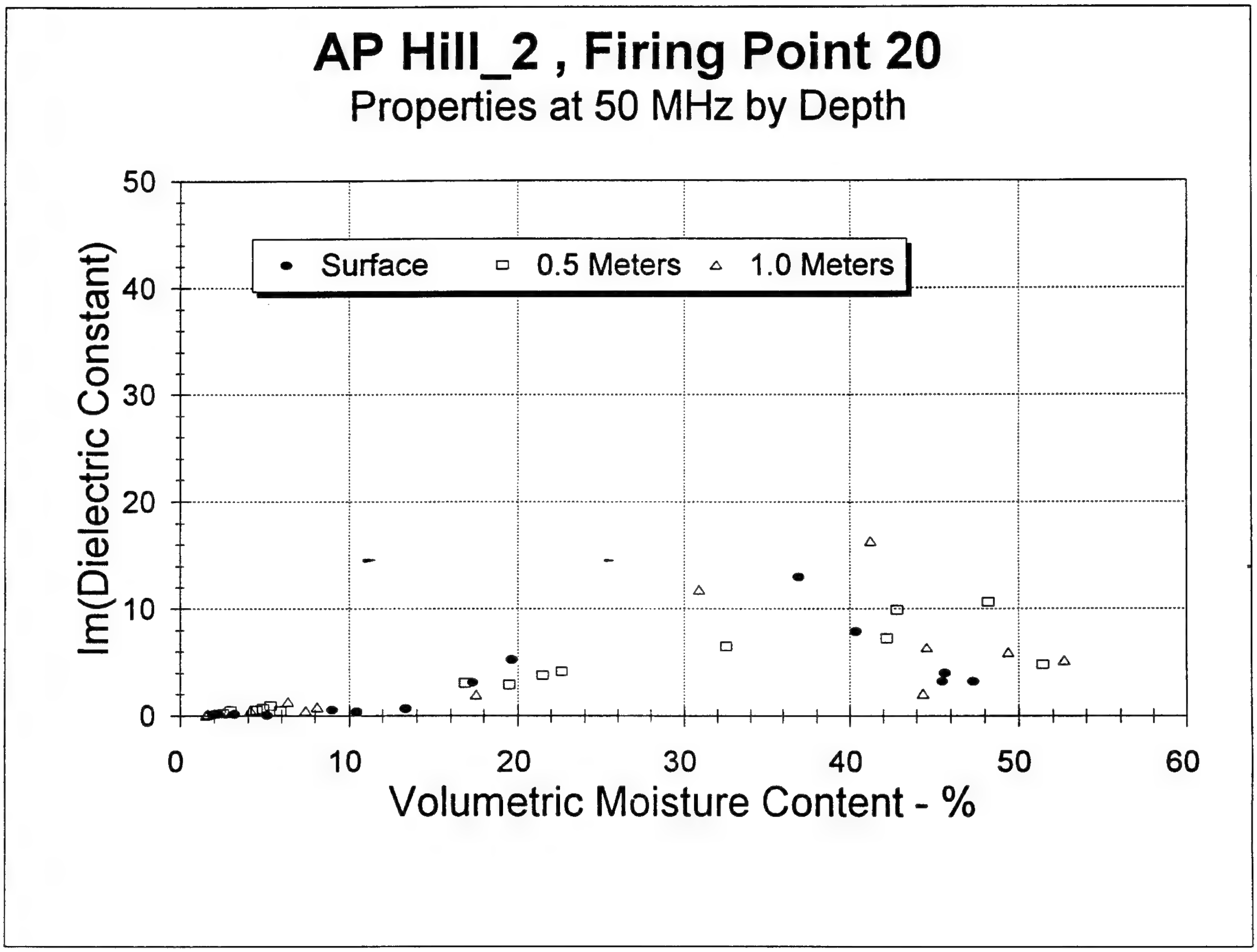
AP Hill_2
Properties at 50 MHz , All Depths
Firing Point 20
Firing Point 22
Loss Tangent
10
1
0.1
0.01
0.001
0
10
20
30
40
50
60
Volumetric Moisture Content - %

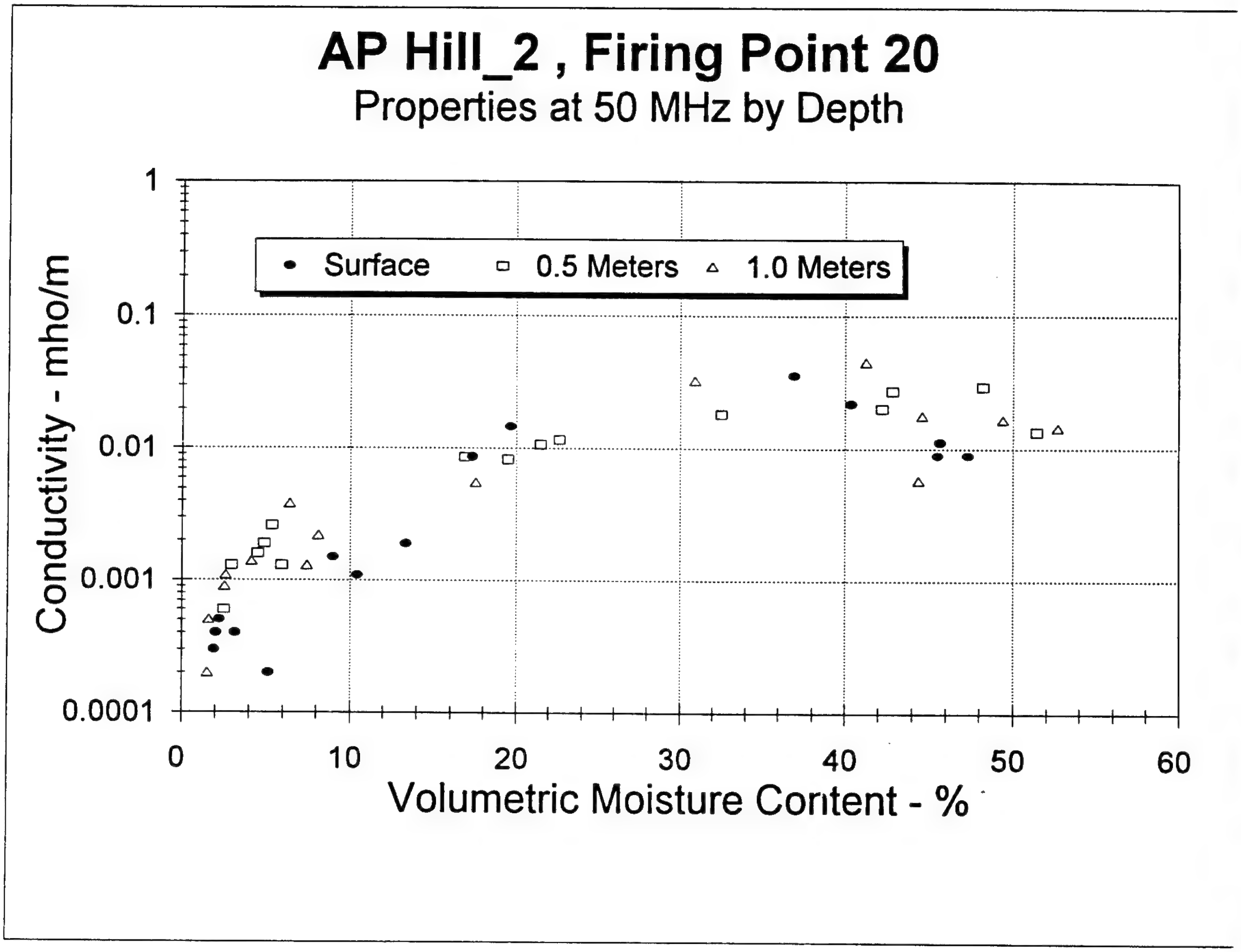


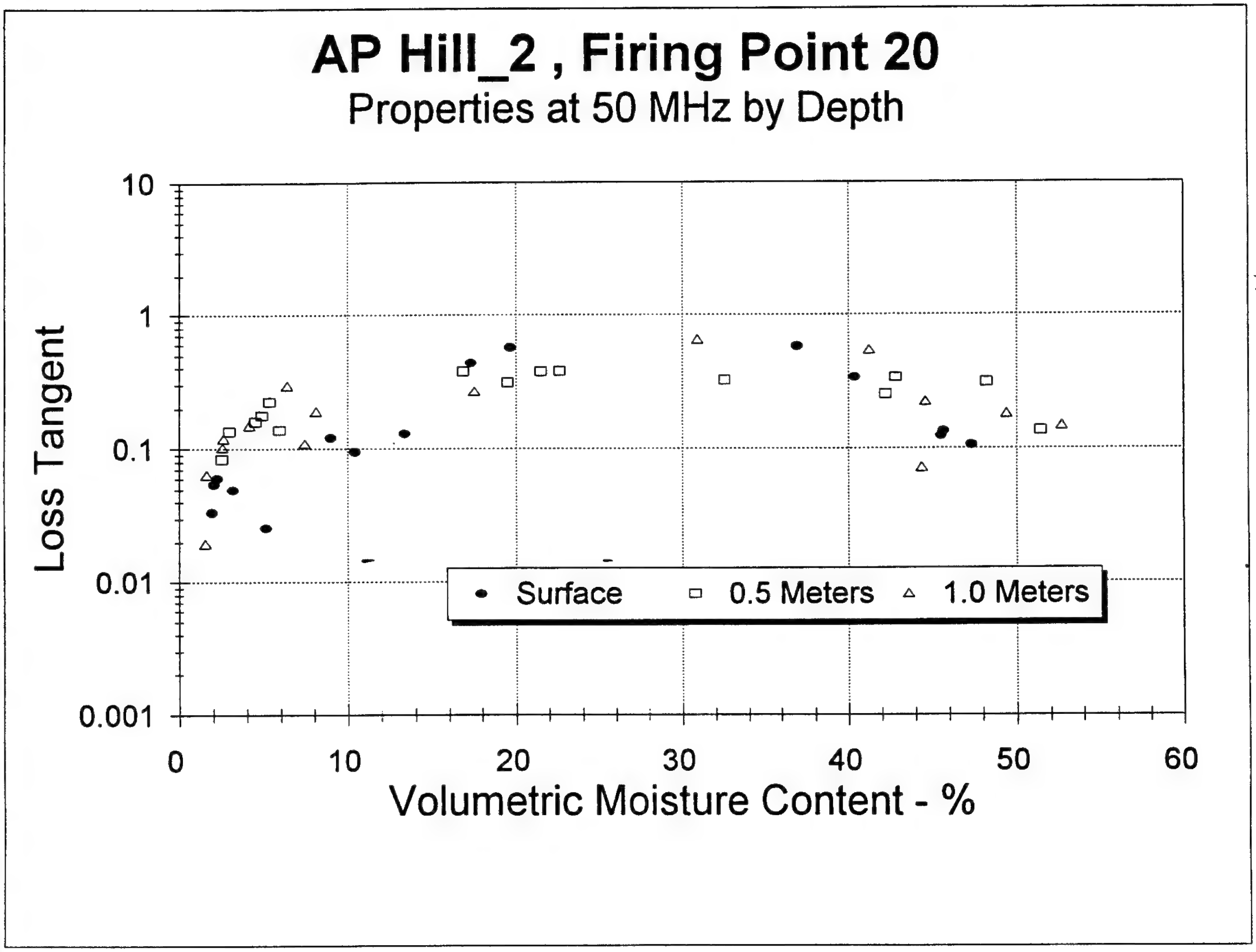
AP Hill_2
Properties at 50 MHz , All Depths
Firing Point 20
Firing Point 22
100
10
1
0.1
Attenuation - dB/m
0
10
20
30
40
50
60
Volumetric Moisture Content - %


AP Hill_2
Properties at 50 MHz , All Depths
Firing Point 20
Firing Point 22
Normalized Phase Velocity
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
10
20
30
40
50
60
Volumetric Moisture Content - %

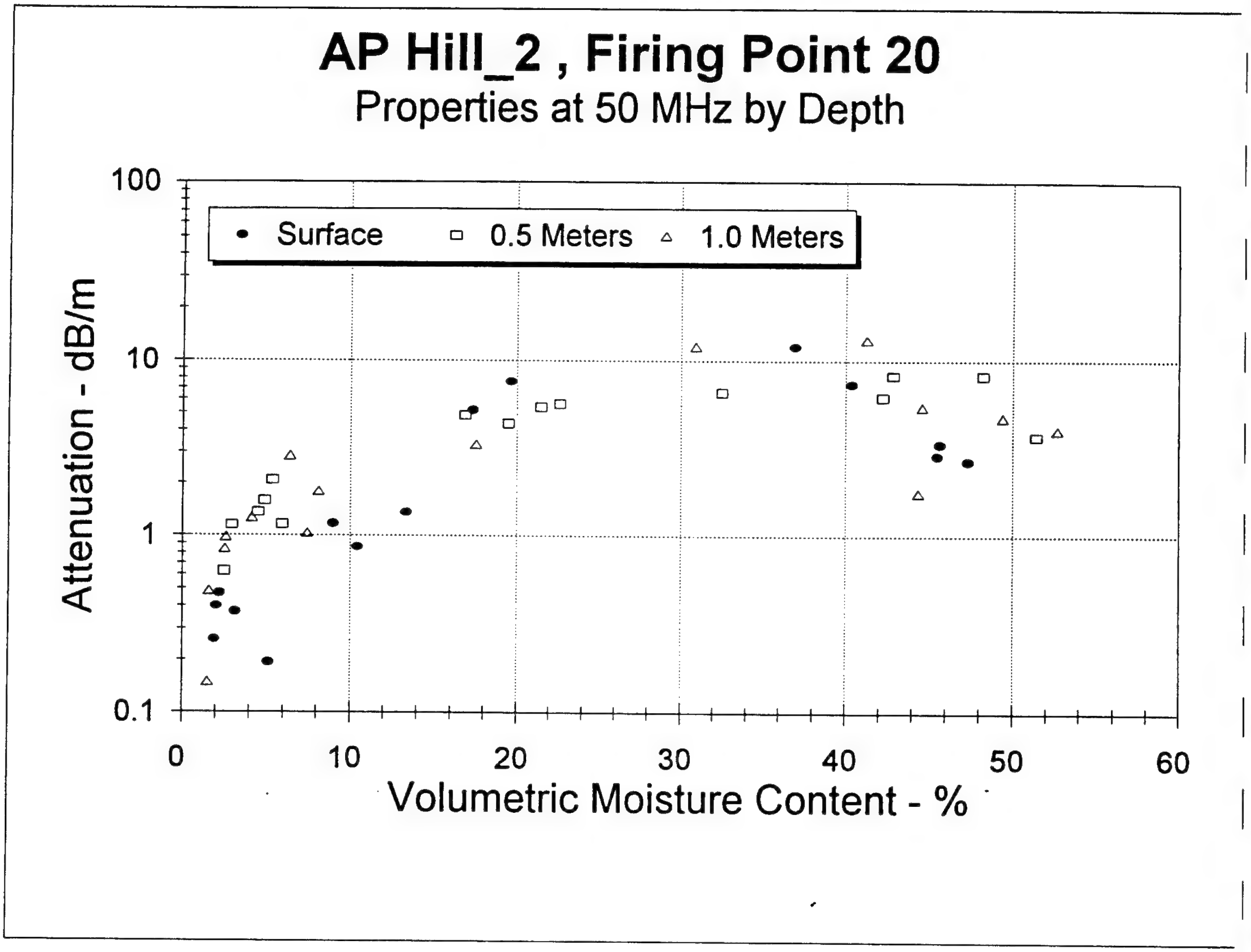

AP Hill_2 , Firing Point 20
Properties at 50 MHz by Depth
Surface
0.5 Meters
1.0 Meters
Re(Dielectric Constant)
Volumetric Moisture Content - %
0
10
20
30
40
50
60

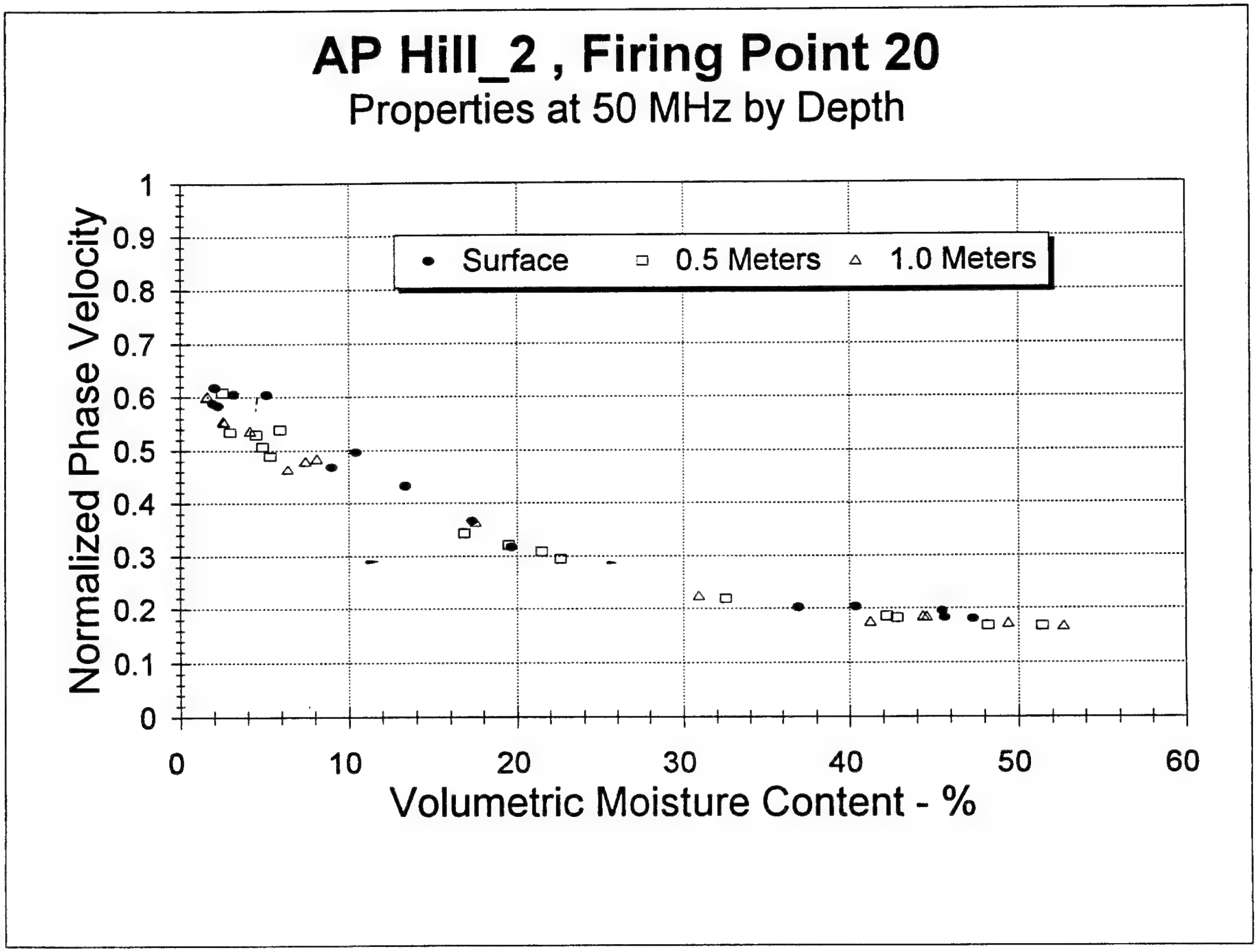

AP Hill_2 , Firing Point 20
Properties at 50 MHz by Depth
Surface
0.5 Meters
1.0 Meters
Im(Dielectric Constant)
0
10
20
30
40
50
60
Volumetric Moisture Content - %

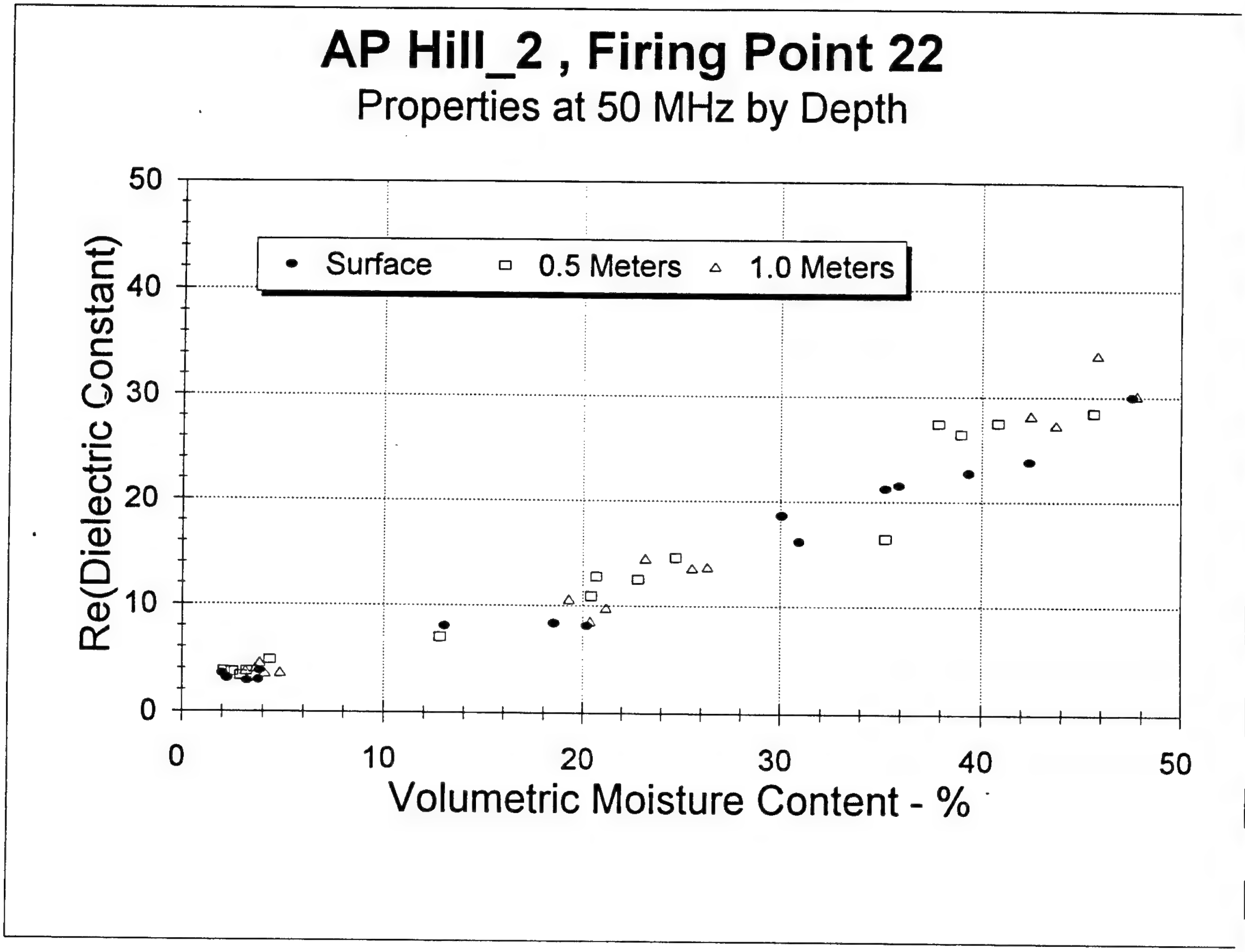

AP Hill_2 , Firing Point 20
Properties at 50 MHz by Depth
Surface
0.5 Meters
1.0 Meters
Conductivity - mho/m
1
0.1
0.01
0.001
0.0001
0
10
20
30
40
50
60
Volumetric Moisture Content - %

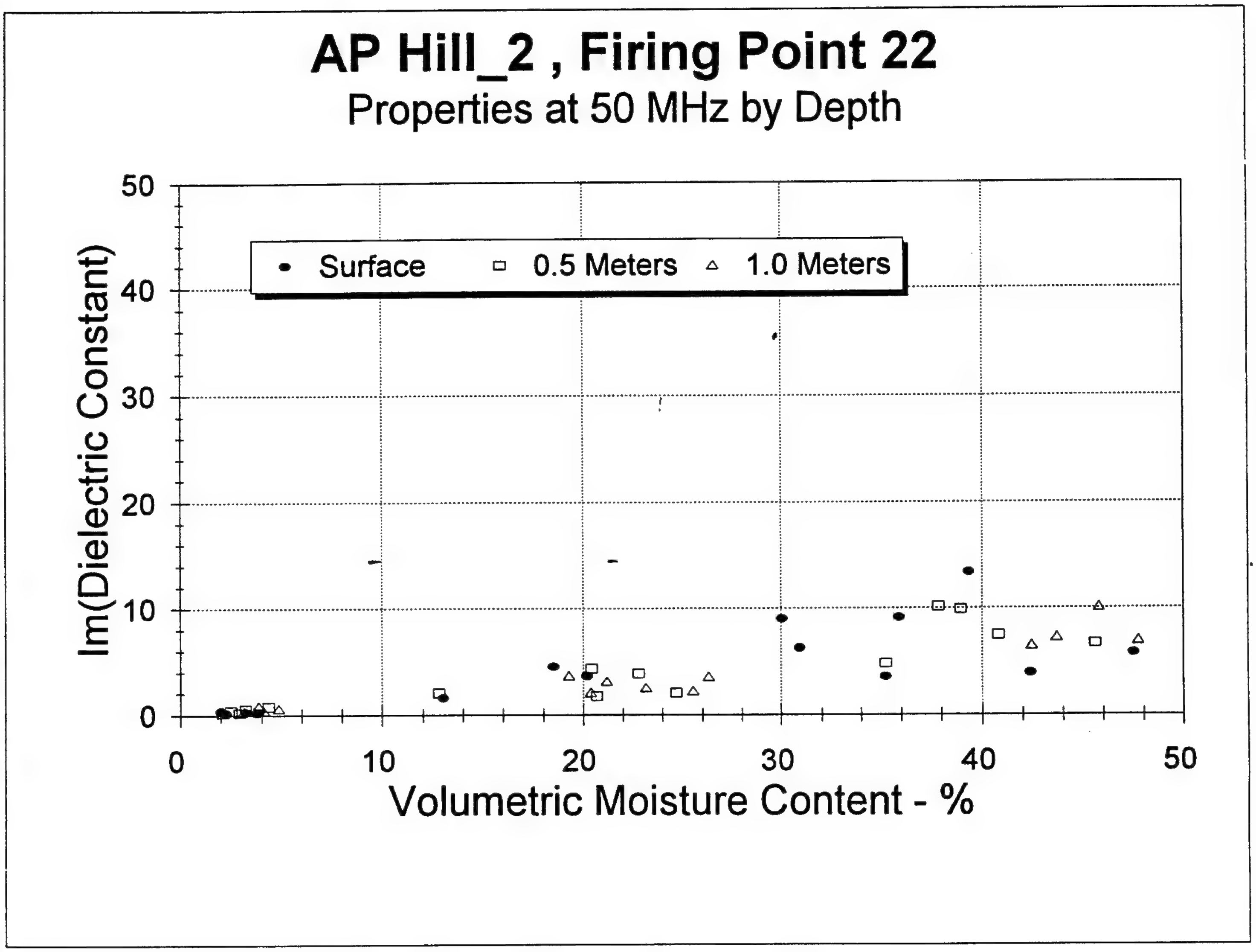


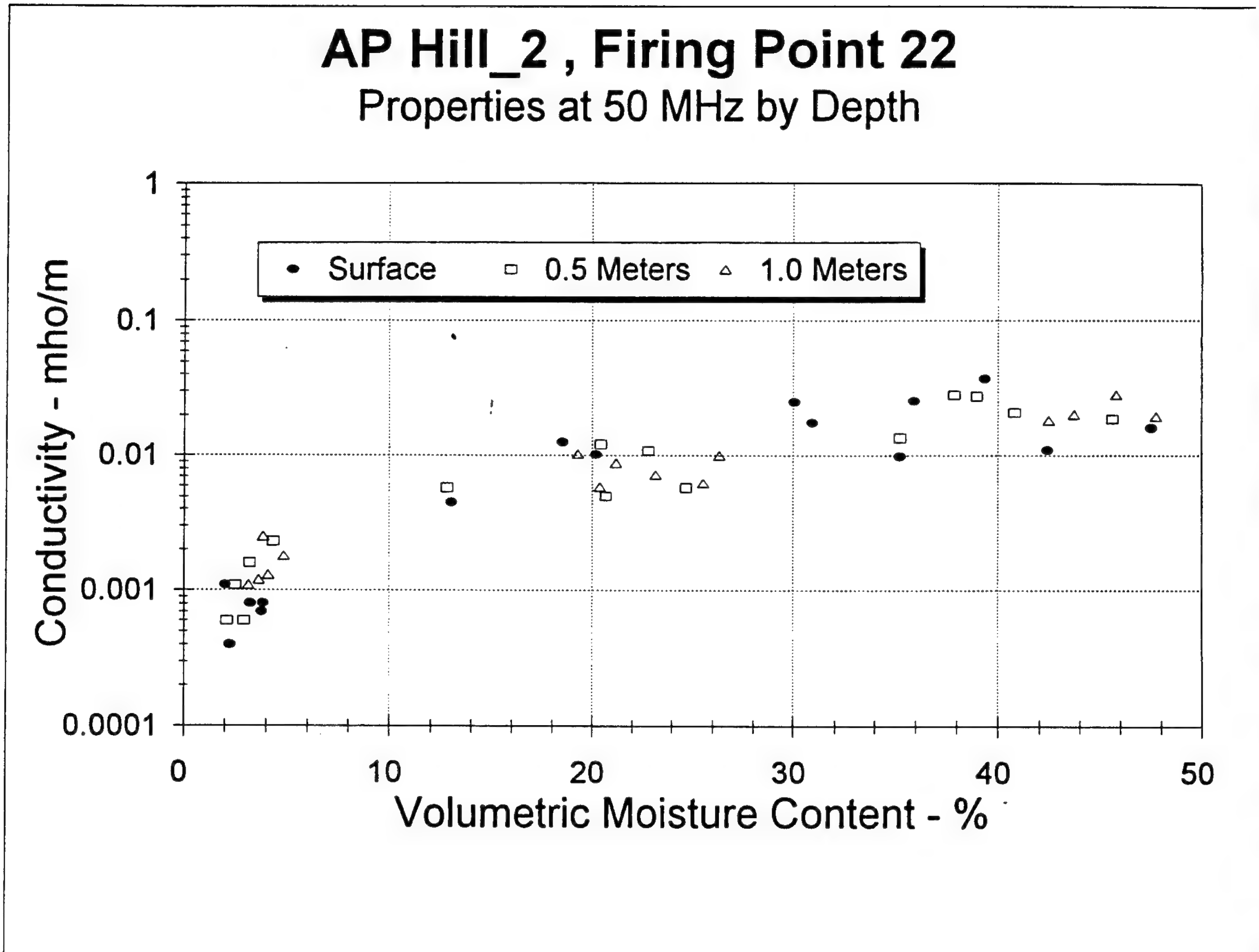
AP Hill_2 , Firing Point 20
Properties at 50 MHz by Depth
Loss Tangent
10
1
0.1
0.01
0.001
0
10
20
30
40
50
60
Volumetric Moisture Content - %
Surface
0.5 Meters
1.0 Meters


AP Hill_2 , Firing Point 20
Properties at 50 MHz by Depth
Surface
0.5 Meters
1.0 Meters
Attenuation - dB/m
100
10
1
0.1
0
10
20
30
40
50
60
Volumetric Moisture Content - %

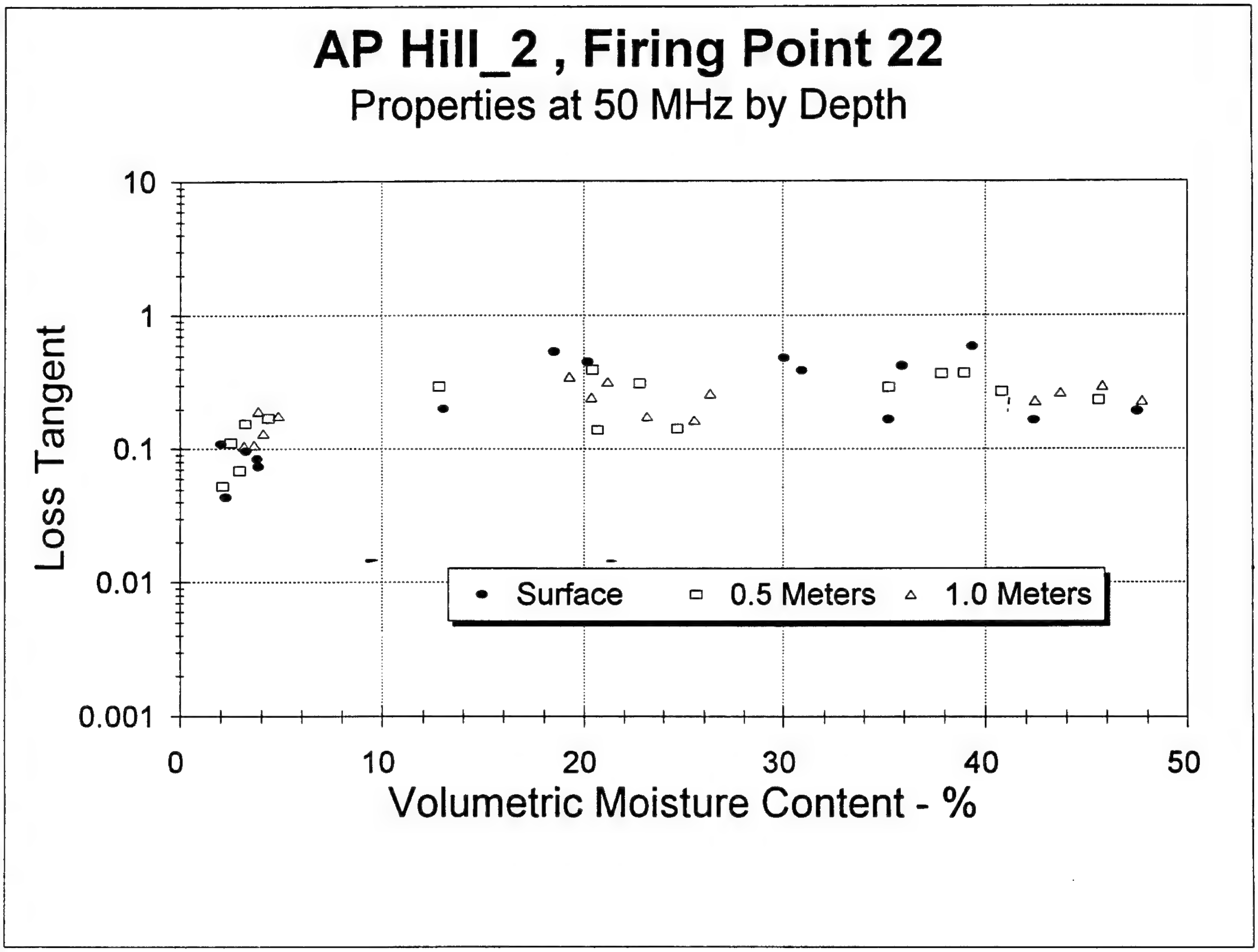

AP Hill_2 , Firing Point 20
Properties at 50 MHz by Depth
Surface
0.5 Meters
1.0 Meters
Normalized Phase Velocity
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
10
20
30
40
50
60
Volumetric Moisture Content - %


AP Hill_2 , Firing Point 22
Properties at 50 MHz by Depth
Surface
0.5 Meters
1.0 Meters
Re(Dielectric Constant)
50
40
30
20
10
0
0
10
20
30
40
50
Volumetric Moisture Content - %

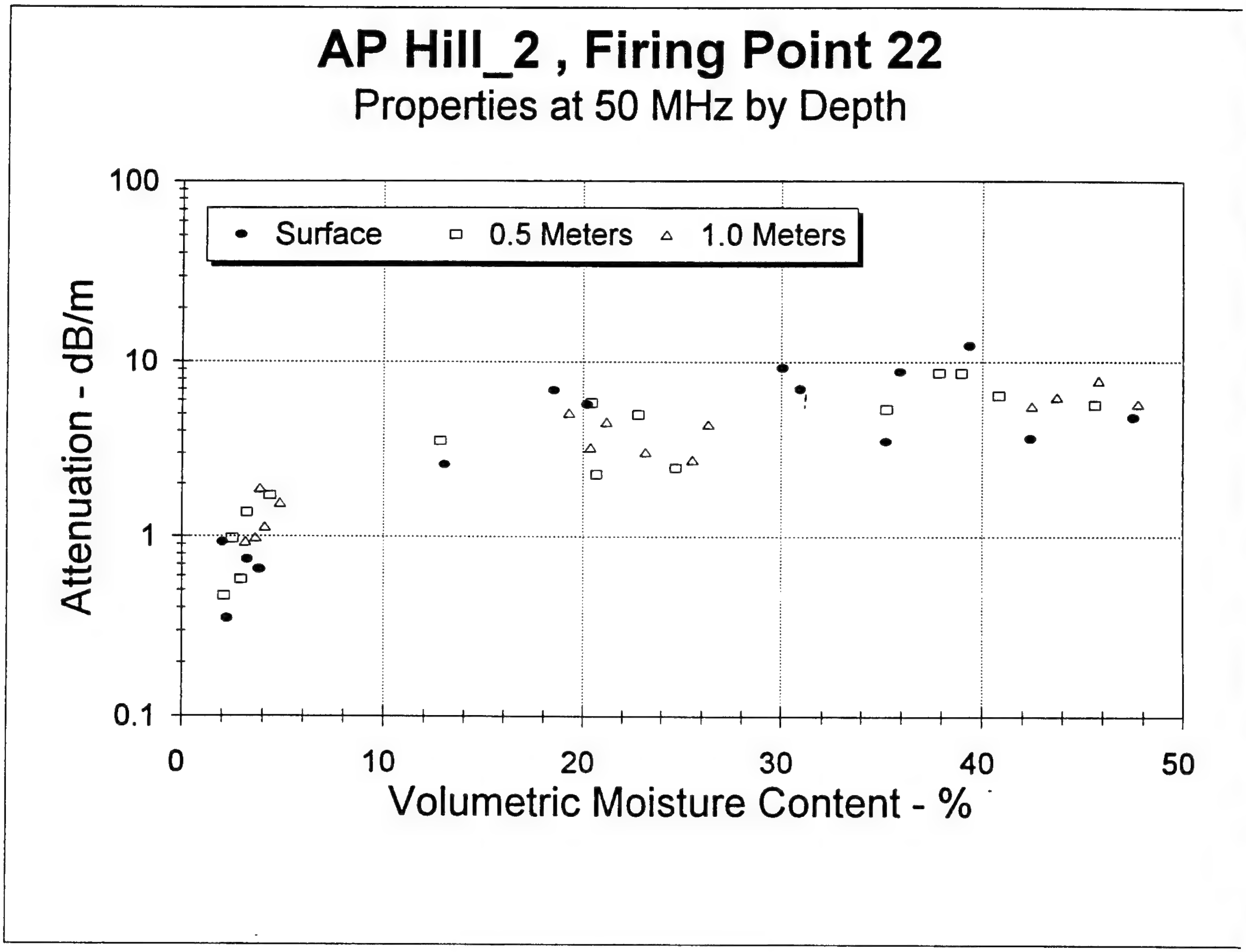

AP Hill_2 , Firing Point 22
Properties at 50 MHz by Depth
Surface
0.5 Meters
1.0 Meters
Im(Dielectric Constant)
Volumetric Moisture Content - %
0
10
20
30
40
50



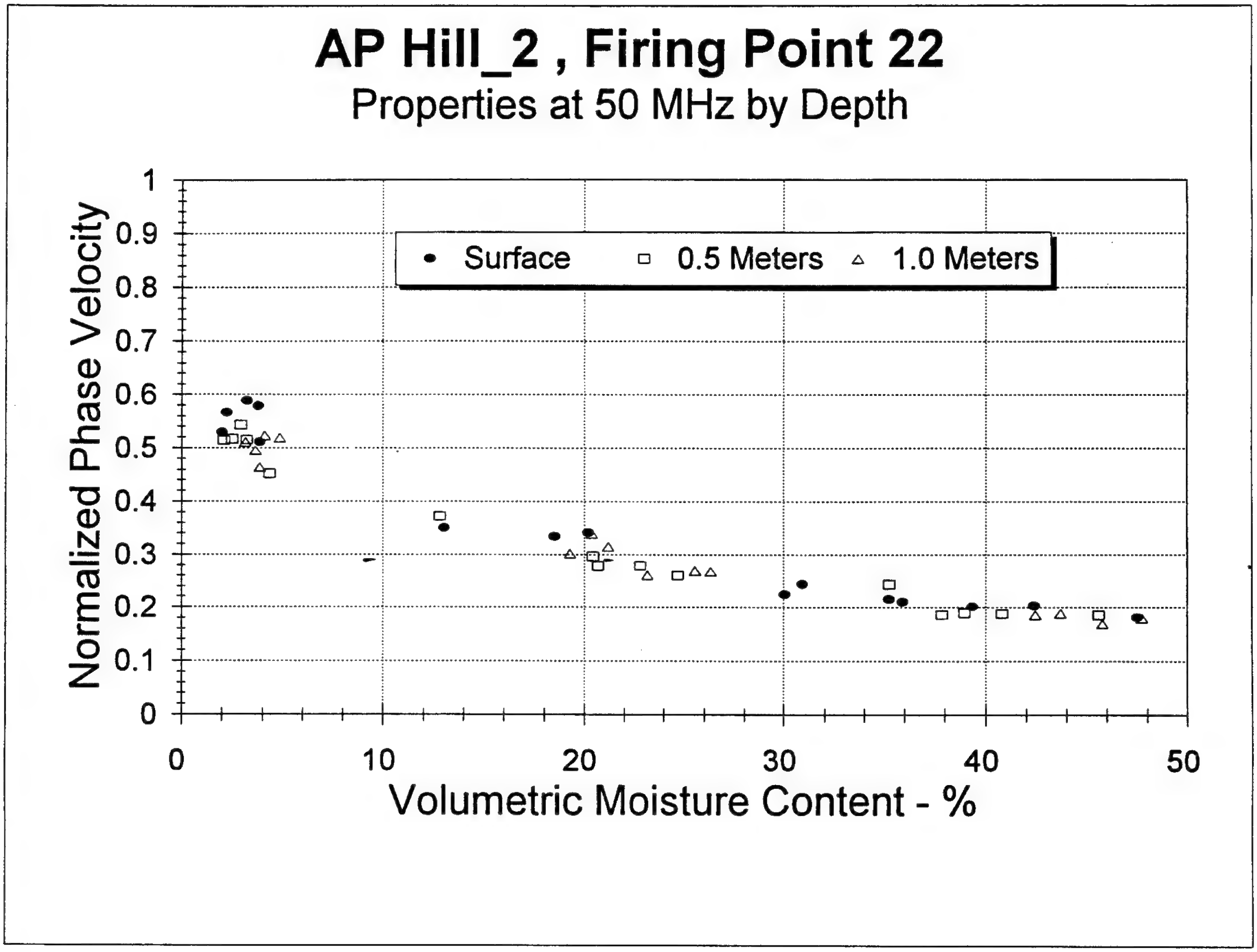
AP Hill_2 , Firing Point 22
Properties at 50 MHz by Depth
Surface
0.5 Meters
1.0 Meters
1
0.1
0.01
0.001
0.0001
Conductivity - mho/m
0
10
20
30
40
50
Volumetric Moisture Content - %



AP Hill_2 , Firing Point 22
Properties at 50 MHz by Depth
Loss Tangent
10
1
0.1
0.01
0.001
0
10
20
30
40
50
Volumetric Moisture Content - %
Surface
0.5 Meters
1.0 Meters



AP Hill_2 , Firing Point 22
Properties at 50 MHz by Depth
Surface
0.5 Meters
1.0 Meters
Attenuation - dB/m
100
10
1
0.1
0
10
20
30
40
50
Volumetric Moisture Content - %


AP Hill_2 , Firing Point 22
Properties at 50 MHz by Depth
Surface
0.5 Meters
1.0 Meters
Normalized Phase Velocity
Volumetric Moisture Content - %
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
10
20
30
40
50

Fort A.P. Hill_2
Properties at 100 Mhz

Fort AP Hill_2 Soil Properties at 100 MHz

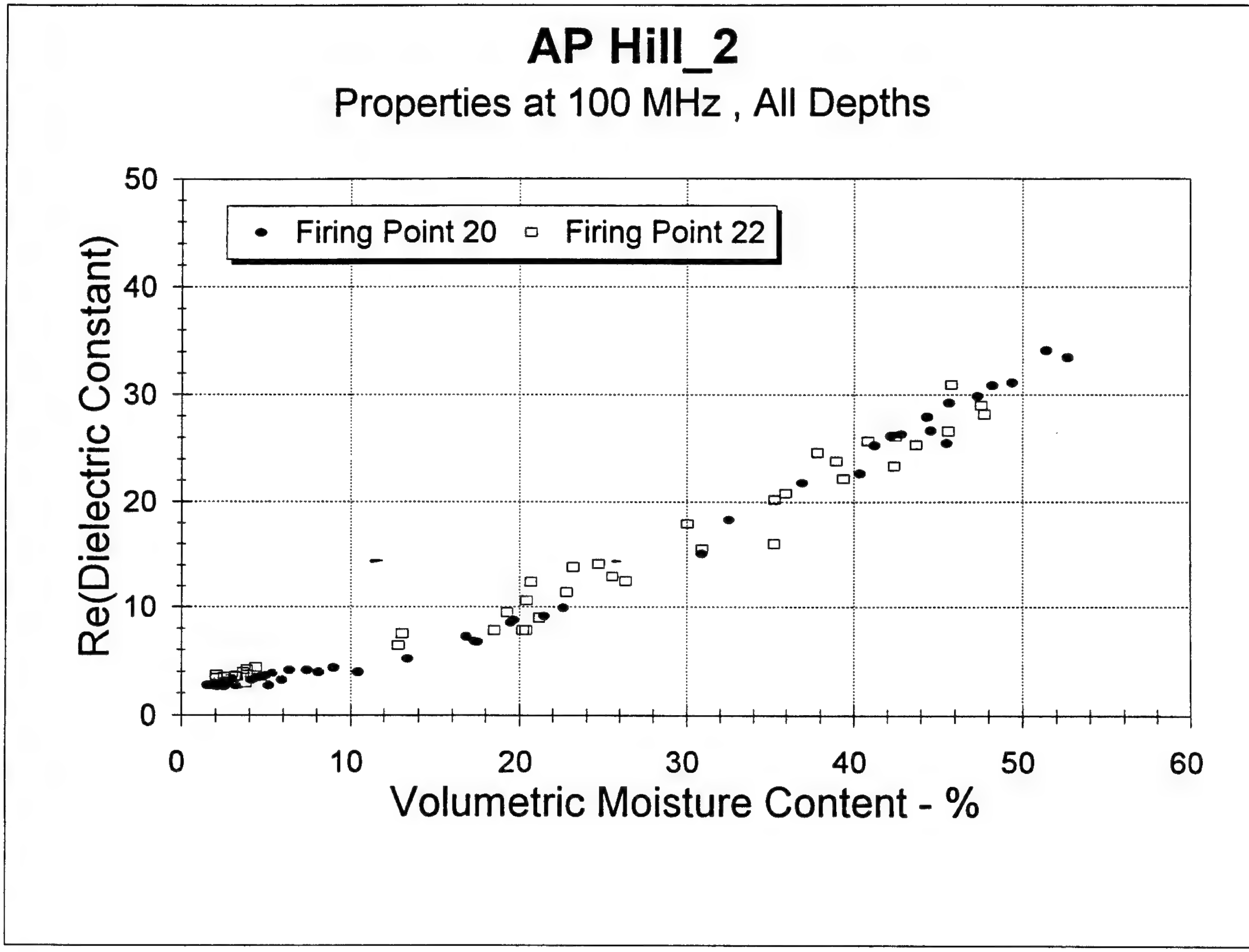
Firing Point 20

File Name	Vol Moist	Dry Dens g/cc	Re(eps)	Im(eps)	Cond mho/m	Loss Tan	Attn dB/m	Norm Vel
200_1b	2.57	1.40	3.08	0.29	0.002	0.09	1.48	0.57
200_1d	2.65	1.40	3.12	0.33	0.002	0.11	1.71	0.57
200_1w	49.42	1.40	31.16	4.18	0.023	0.13	6.80	0.18
200_2b	5.97	1.21	3.25	0.35	0.002	0.11	1.76	0.55
200_2d	2.52	1.21	2.62	0.18	0.001	0.07	1.02	0.62
200_2w	51.44	1.21	34.13	3.44	0.019	0.10	5.35	0.17
200_sb	9.01	1.39	4.37	0.39	0.002	0.09	1.71	0.48
200_sd	2.27	1.39	2.85	0.15	0.001	0.05	0.79	0.59
200_sw	47.36	1.39	29.87	2.25	0.013	0.08	3.74	0.18
20122_1b	30.94	1.53	15.11	7.65	0.043	0.51	17.39	0.25
20122_1d	6.41	1.53	4.14	1.06	0.006	0.26	4.69	0.49
20122_1w	41.25	1.53	25.32	10.82	0.060	0.43	19.14	0.19
20122_2b	16.89	1.37	7.27	2.15	0.012	0.30	7.18	0.37
20122_2d	2.98	1.37	3.31	0.39	0.002	0.12	1.97	0.55
20122_2w	48.22	1.37	30.92	7.37	0.041	0.24	11.97	0.18
20122_sb	17.37	1.47	6.83	1.76	0.010	0.26	6.09	0.38
20122_sd	3.19	1.47	2.75	0.12	0.001	0.04	0.67	0.60
20122_sw	40.39	1.47	22.71	4.49	0.025	0.20	8.52	0.21
20123_1b	8.11	1.33	3.98	0.60	0.003	0.15	2.71	0.50
20123_1d	1.61	1.33	2.72	0.16	0.001	0.06	0.89	0.61
20123_1w	52.69	1.33	33.49	3.83	0.021	0.11	6.02	0.17
20123_2b	21.49	1.66	9.15	2.63	0.015	0.29	7.82	0.33
20123_2d	4.55	1.66	3.42	0.47	0.003	0.14	2.29	0.54
20123_2w	32.55	1.66	18.31	4.44	0.025	0.24	9.38	0.23
20123_sb	19.71	1.54	8.78	2.92	0.016	0.33	8.86	0.33
20123_sd	1.95	1.54	2.88	0.09	0.001	0.03	0.49	0.59
20123_sw	36.96	1.54	21.80	7.00	0.039	0.32	13.46	0.21
2027_1b	7.44	1.53	4.15	0.34	0.002	0.08	1.51	0.49
2027_1d	1.54	1.53	2.76	0.05	0.000	0.02	0.28	0.60
2027_1w	44.38	1.53	27.96	1.65	0.009	0.06	2.83	0.19
2027_2b	22.63	1.53	9.94	2.88	0.016	0.29	8.23	0.31
2027_2d	5.34	1.53	3.84	0.73	0.004	0.19	3.37	0.51
2027_2w	42.86	1.53	26.36	6.69	0.037	0.25	11.76	0.19
2027_sb	10.49	1.44	3.95	0.26	0.002	0.07	1.21	0.50
2027_sd	5.16	1.44	2.75	0.07	0.000	0.03	0.40	0.60
2027_sw	45.55	1.44	25.55	2.02	0.011	0.08	3.64	0.20
2065_1b	17.55	1.47	6.79	1.39	0.008	0.20	4.83	0.38
2065_1d	4.15	1.47	3.28	0.42	0.002	0.13	2.13	0.55
2065_1w	44.58	1.47	26.68	4.39	0.024	0.16	7.70	0.19
2065_2b	19.52	1.48	8.58	2.10	0.012	0.25	6.49	0.34
2065_2d	4.91	1.48	3.61	0.55	0.003	0.15	2.65	0.53
2065_2w	42.22	1.48	26.19	5.15	0.029	0.20	9.10	0.19
2065_sb	13.39	1.37	5.20	0.44	0.002	0.08	1.75	0.44
2065_sd	2.09	1.37	2.62	0.13	0.001	0.05	0.71	0.62
2065_sw	45.70	1.37	29.26	2.49	0.014	0.09	4.18	0.18

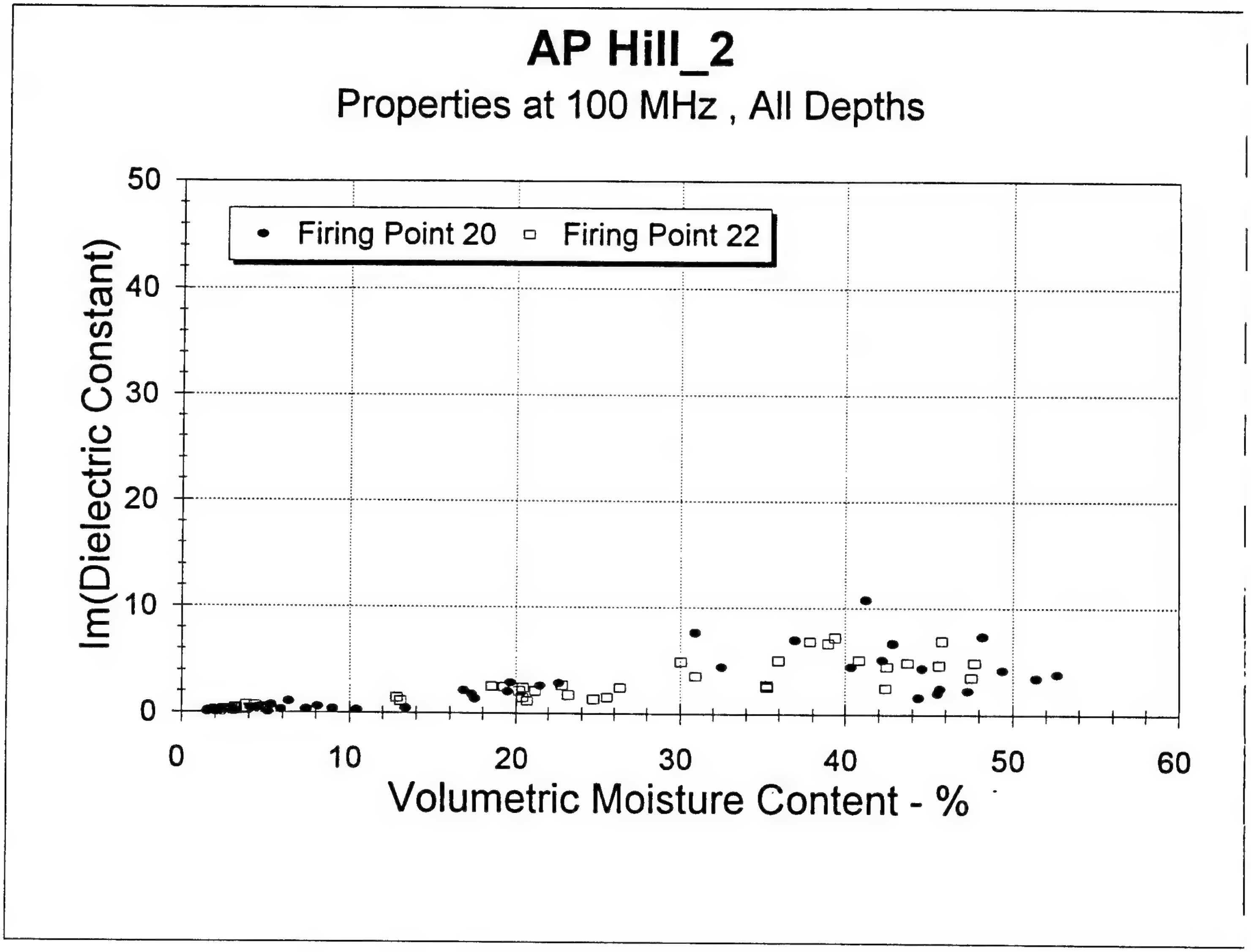
Fort AP Hill_2 Soil Properties at 100 MHz

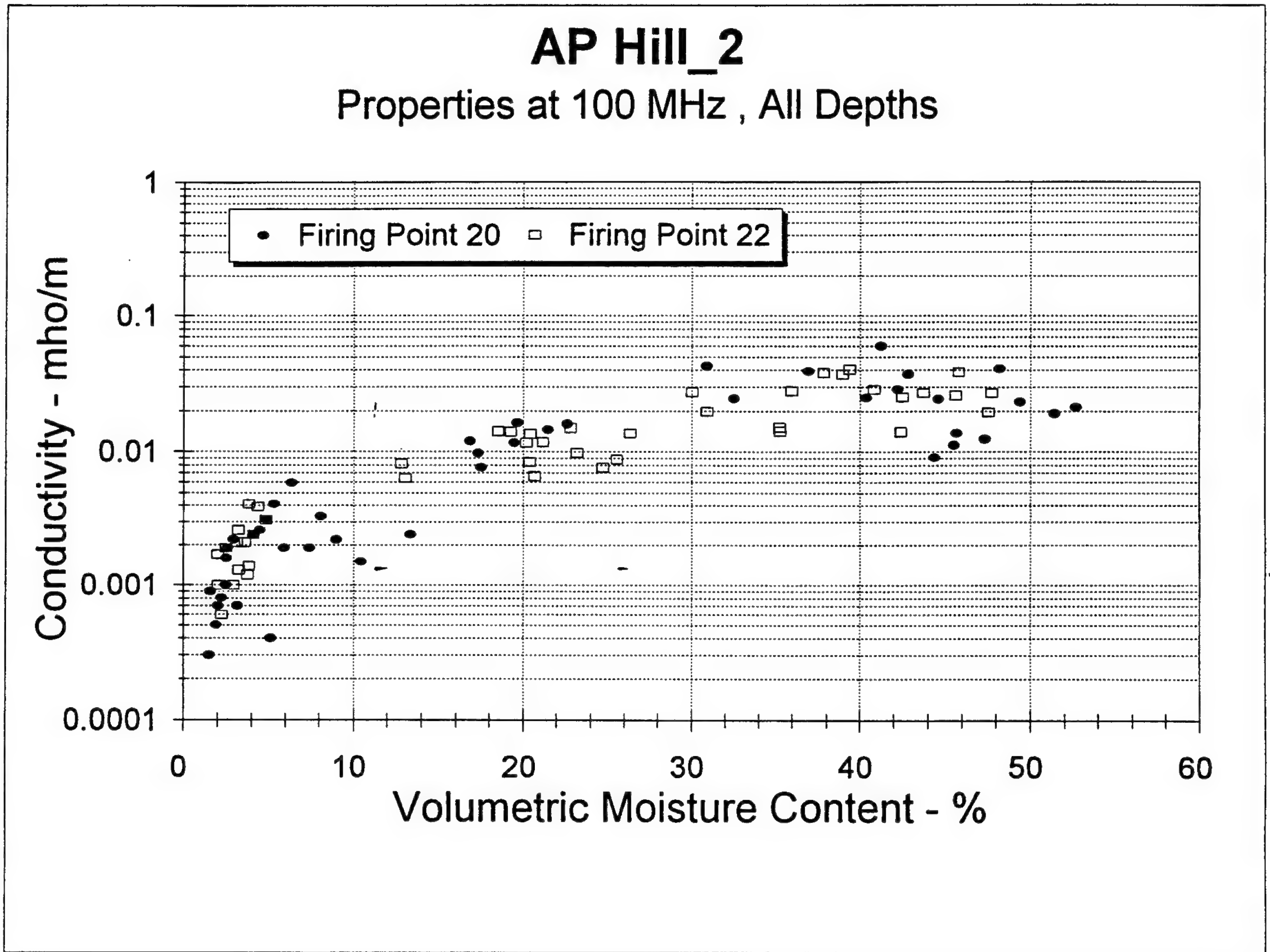
Firing Point 22

File Name	Vol Moist	Dry Dens g/cc	Re(eps)	Im(eps)	Cond mho/m	Loss Tan	Attn dB/m	Norm Vel
22122_1b	19.30	1.53	9.55	2.53	0.014	0.27	7.39	0.32
22122_1d	3.88	1.53	4.25	0.73	0.004	0.17	3.20	0.48
22122_1w	45.79	1.53	30.98	6.96	0.039	0.22	11.31	0.18
22122_2b	20.45	1.83	10.65	2.42	0.014	0.23	6.71	0.30
22122_2d	2.94	1.83	3.33	0.19	0.001	0.06	0.94	0.55
22122_2w	35.24	1.83	16.06	2.73	0.015	0.17	6.18	0.25
22122_sb	13.05	1.69	7.58	1.15	0.006	0.15	3.80	0.36
22122_sd	2.04	1.69	3.40	0.30	0.002	0.09	1.49	0.54
22122_sw	35.25	1.69	20.23	2.55	0.014	0.13	5.15	0.22
22123_1b	21.20	1.53	9.01	2.11	0.012	0.23	6.36	0.33
22123_1d	4.87	1.53	3.58	0.55	0.003	0.15	2.65	0.53
22123_1w	43.69	1.53	25.41	4.87	0.027	0.19	8.75	0.20
22123_2b	12.82	1.51	6.47	1.47	0.008	0.23	5.21	0.39
22123_2d	3.22	1.51	3.57	0.47	0.003	0.13	2.28	0.53
22123_2w	45.59	1.51	26.65	4.68	0.026	0.18	8.21	0.19
22123_sb	18.55	1.55	7.89	2.55	0.014	0.32	8.15	0.35
22123_sd	3.80	1.55	3.00	0.22	0.001	0.07	1.17	0.58
22123_sw	39.36	1.55	22.20	7.26	0.040	0.33	13.83	0.21
2227_1b	26.33	1.51	12.54	2.49	0.014	0.20	6.36	0.28
2227_1d	3.15	1.51	3.60	0.37	0.002	0.10	1.79	0.53
2227_1w	42.47	1.51	26.19	4.54	0.025	0.17	8.03	0.19
2227_2b	37.85	1.66	24.68	6.87	0.038	0.28	12.46	0.20
2227_2d	4.37	1.66	4.47	0.70	0.004	0.16	2.98	0.47
2227_2w	38.96	1.66	23.87	6.70	0.037	0.28	12.36	0.20
2227_sb	47.54	1.31	29.04	3.54	0.020	0.12	5.97	0.19
2227_sd	2.27	1.31	3.04	0.12	0.001	0.04	0.60	0.57
2227_sw	42.39	1.31	23.40	2.54	0.014	0.11	4.76	0.21
222_1b	20.41	1.40	7.86	1.52	0.008	0.19	4.89	0.36
222_1d	4.12	1.40	3.43	0.43	0.002	0.12	2.09	0.54
222_1w	47.74	1.40	28.20	4.89	0.027	0.17	8.34	0.19
222_2b	22.82	1.57	11.46	2.70	0.015	0.24	7.19	0.29
222_2d	2.51	1.57	3.53	0.35	0.002	0.10	1.69	0.53
222_2w	40.82	1.57	25.76	5.13	0.029	0.20	9.16	0.20
222_sb	20.23	1.55	7.85	2.11	0.012	0.27	6.79	0.35
222_sd	3.26	1.55	2.89	0.24	0.001	0.08	1.26	0.59
222_sw	35.92	1.55	20.87	5.05	0.028	0.24	9.98	0.22
2265_1b	23.21	1.99	13.82	1.78	0.010	0.13	4.35	0.27
2265_1d	3.65	1.99	3.97	0.37	0.002	0.09	1.70	0.50
2265_1w	25.57	1.99	12.98	1.58	0.009	0.12	3.97	0.28
2265_2b	20.71	1.94	12.42	1.19	0.007	0.10	3.08	0.28
2265_2d	2.09	1.94	3.70	0.18	0.001	0.05	0.87	0.52
2265_2w	24.72	1.94	14.12	1.38	0.008	0.10	3.33	0.27
2265_sb	30.08	1.82	17.95	4.95	0.028	0.28	10.52	0.23
2265_sd	3.87	1.82	3.72	0.25	0.001	0.07	1.18	0.52
2265_sw	30.94	1.82	15.59	3.57	0.020	0.23	8.17	0.25

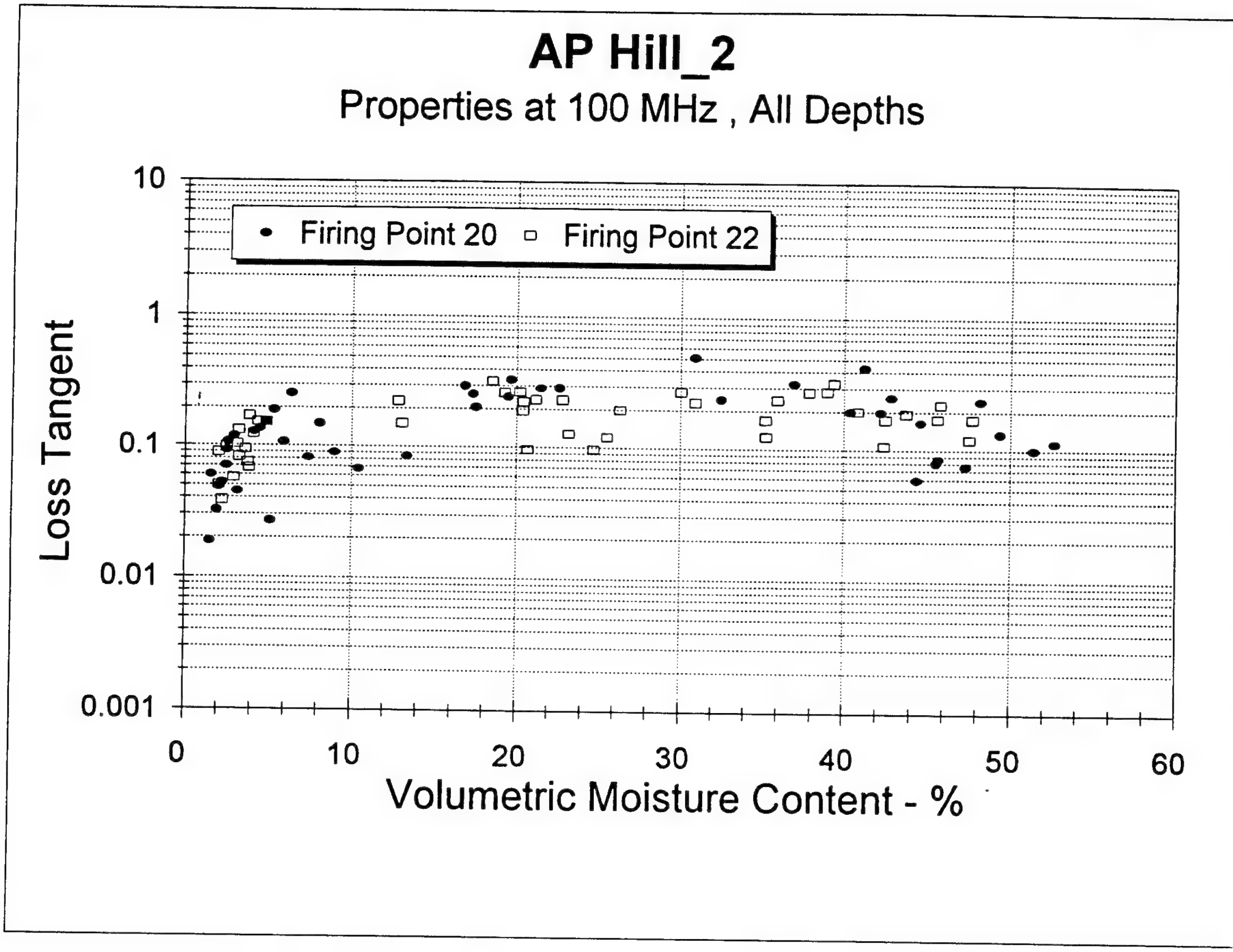


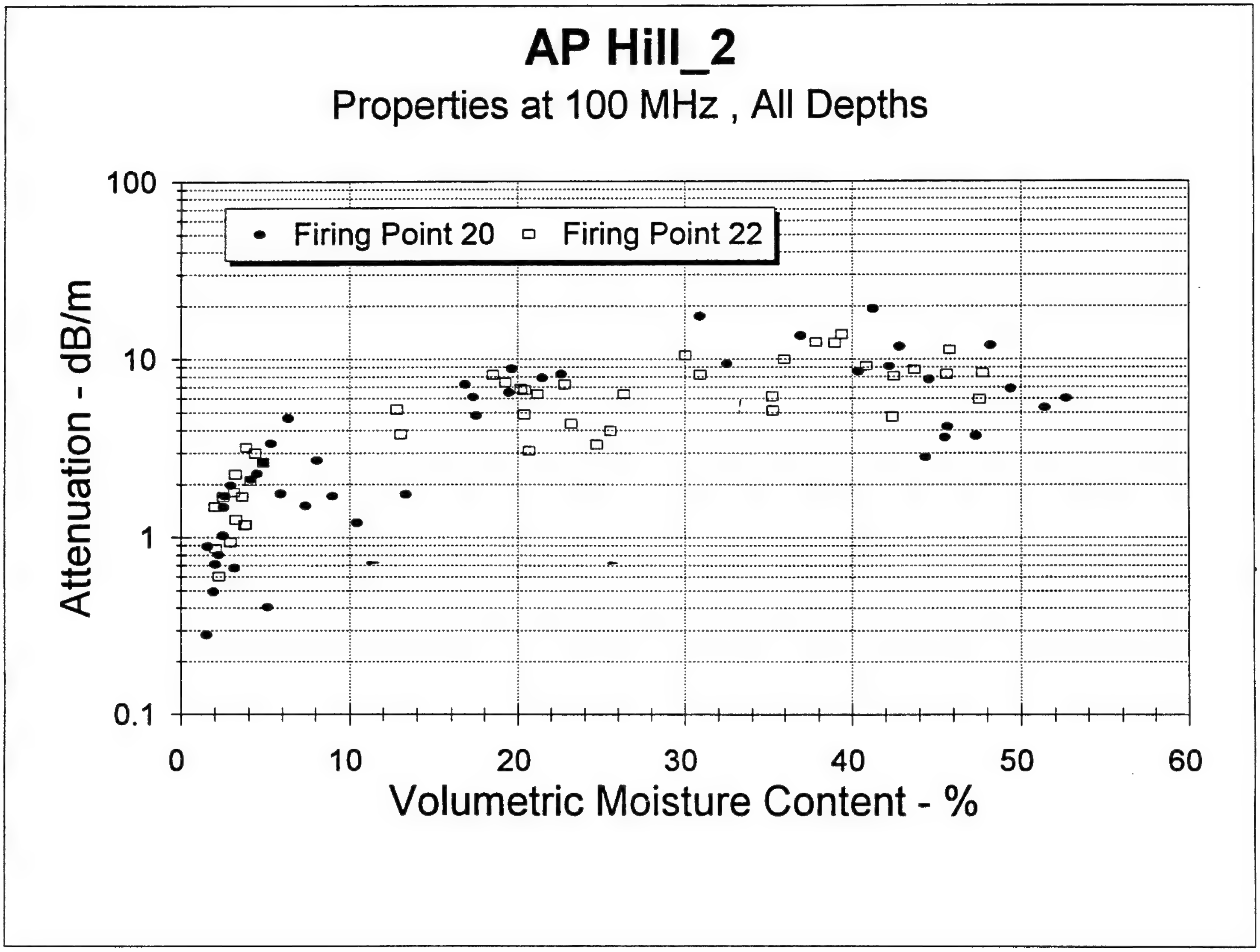
AP Hill_2
Properties at 100 MHz , All Depths
Firing Point 20
Firing Point 22
Re(Dielectric Constant)
0
10
20
30
40
50
0
10
20
30
40
50
60
Volumetric Moisture Content - %


AP Hill_2
Properties at 100 MHz , All Depths
Firing Point 20
Firing Point 22
Im(Dielectric Constant)
Volumetric Moisture Content - %
0
10
20
30
40
50
60

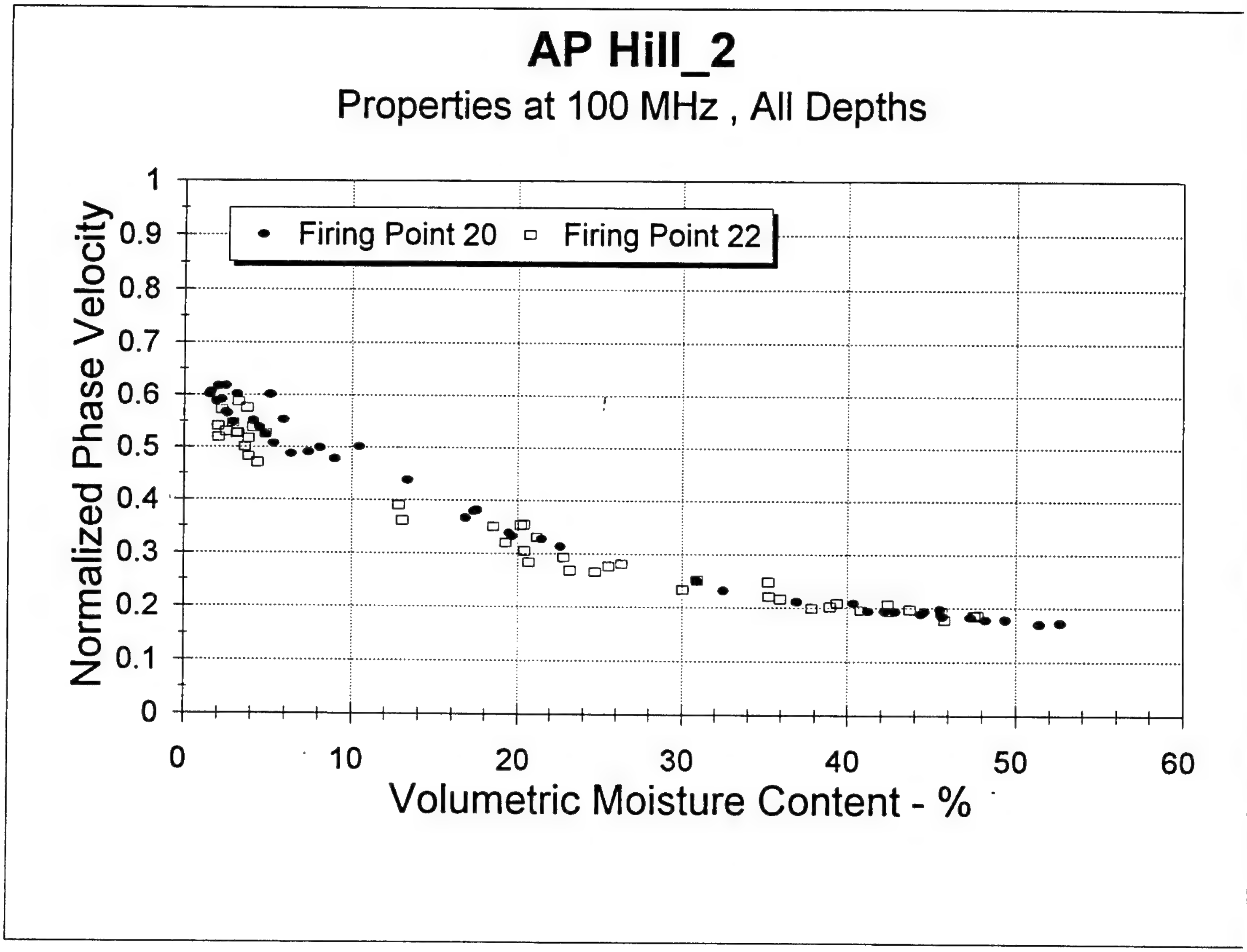


AP Hill_2
Properties at 100 MHz , All Depths
Firing Point 20
Firing Point 22
Conductivity - mho/m
1
0.1
0.01
0.001
0.0001
0
10
20
30
40
50
60
Volumetric Moisture Content - %

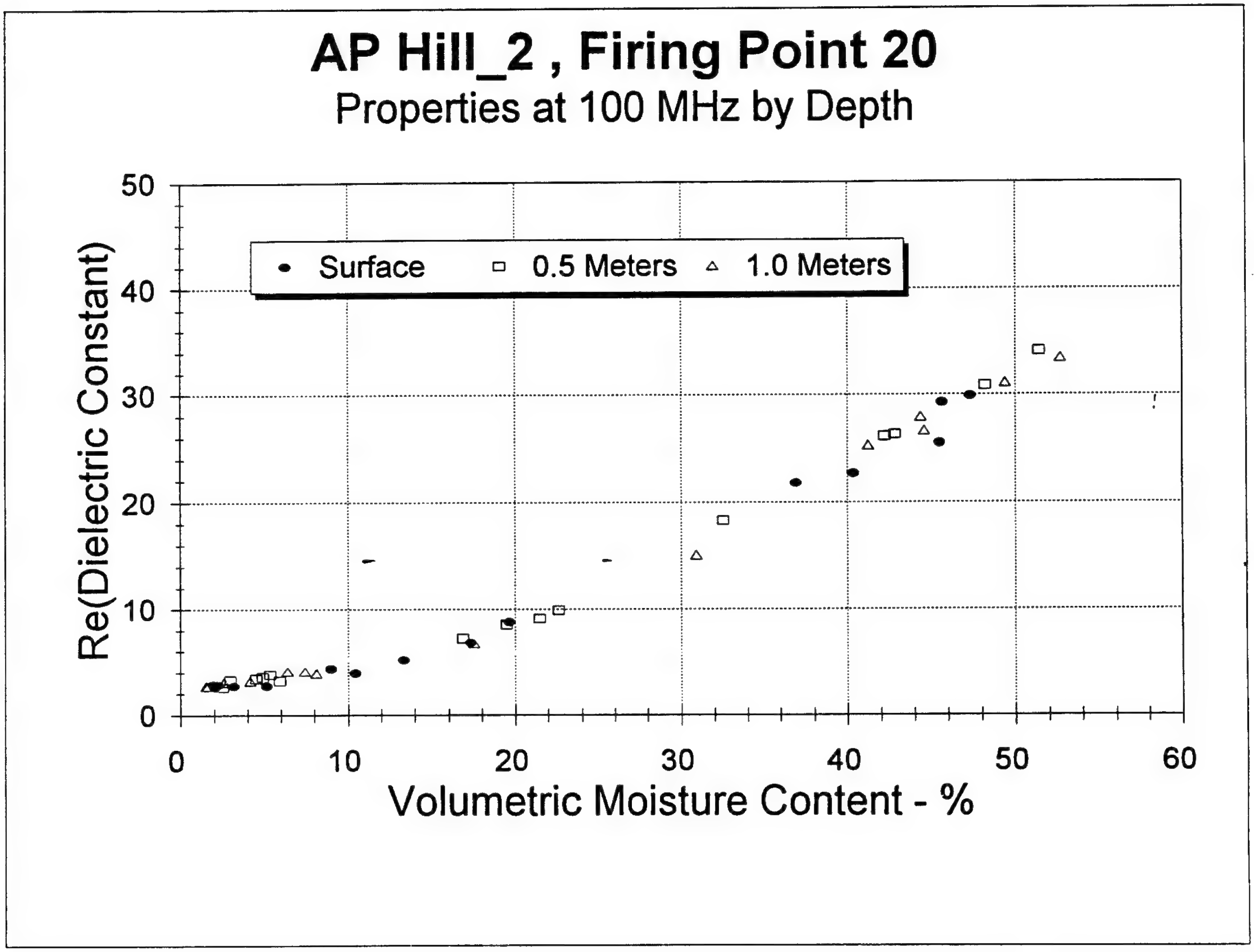

AP Hill_2
Properties at 100 MHz , All Depths
Firing Point 20
Firing Point 22
10
1
0.1
0.01
0.001
Loss Tangent
0
10
20
30
40
50
60
Volumetric Moisture Content - %

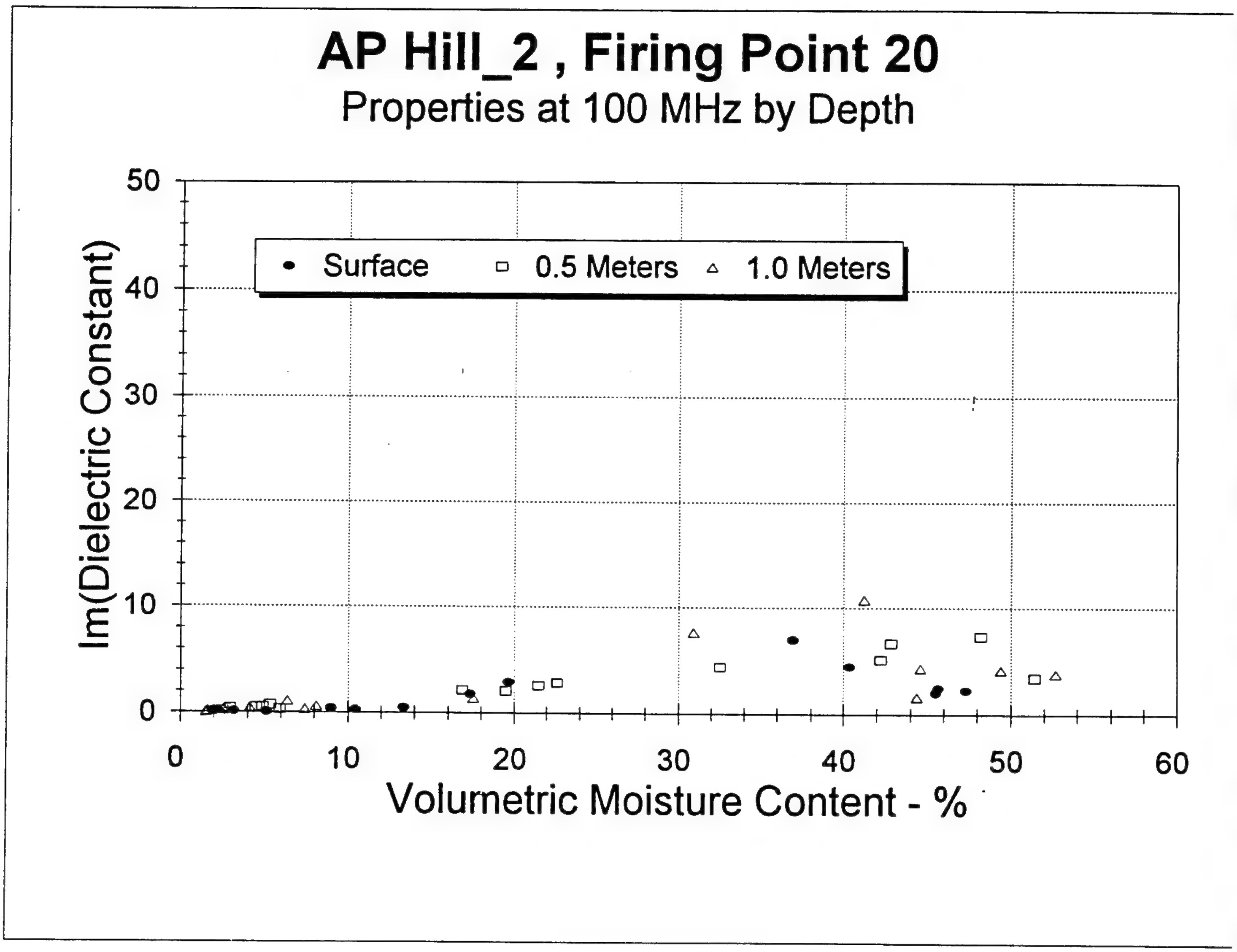


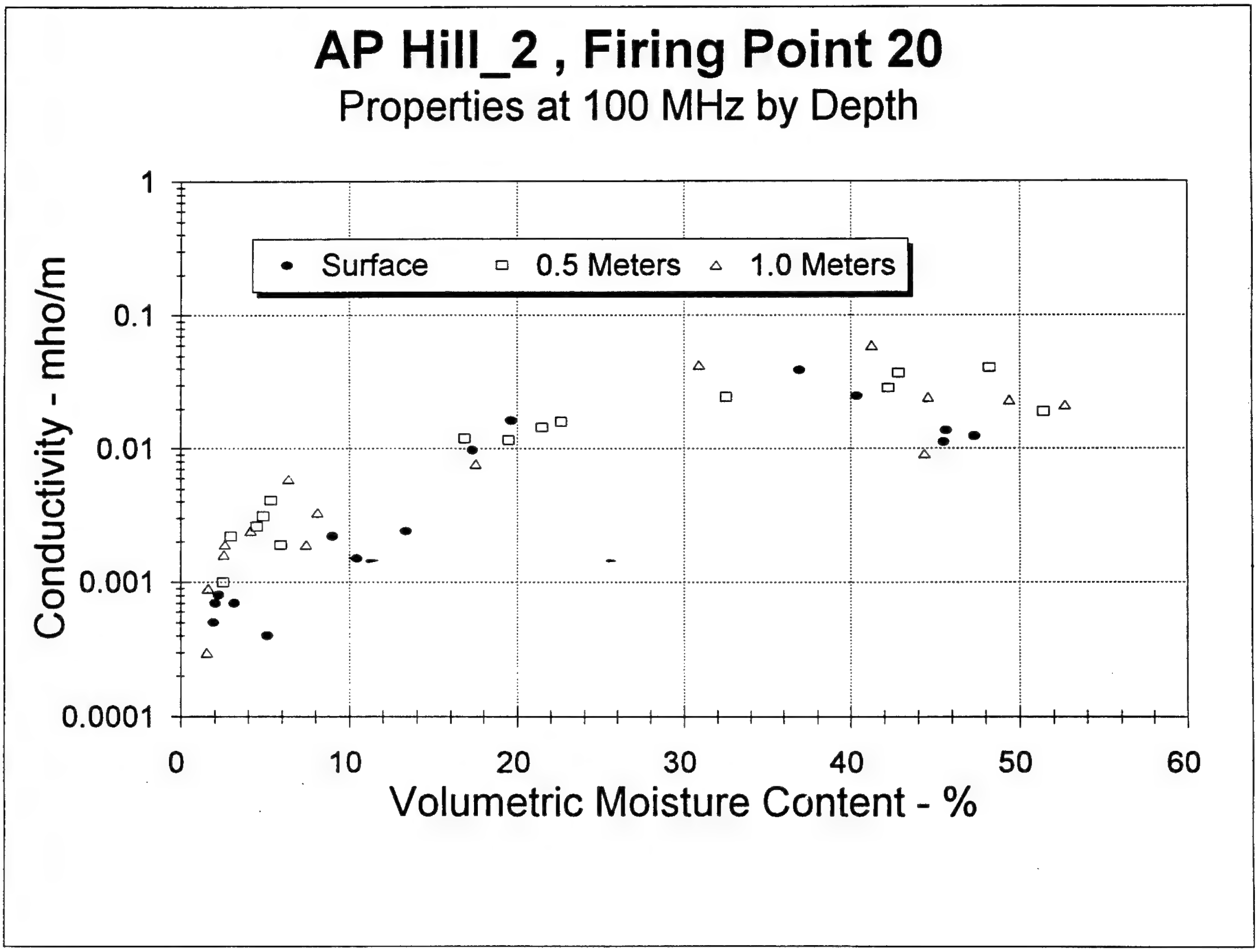
AP Hill_2
Properties at 100 MHz , All Depths
Firing Point 20
Firing Point 22
Attenuation - dB/m
100
10
1
0.1
0
10
20
30
40
50
60
Volumetric Moisture Content - %



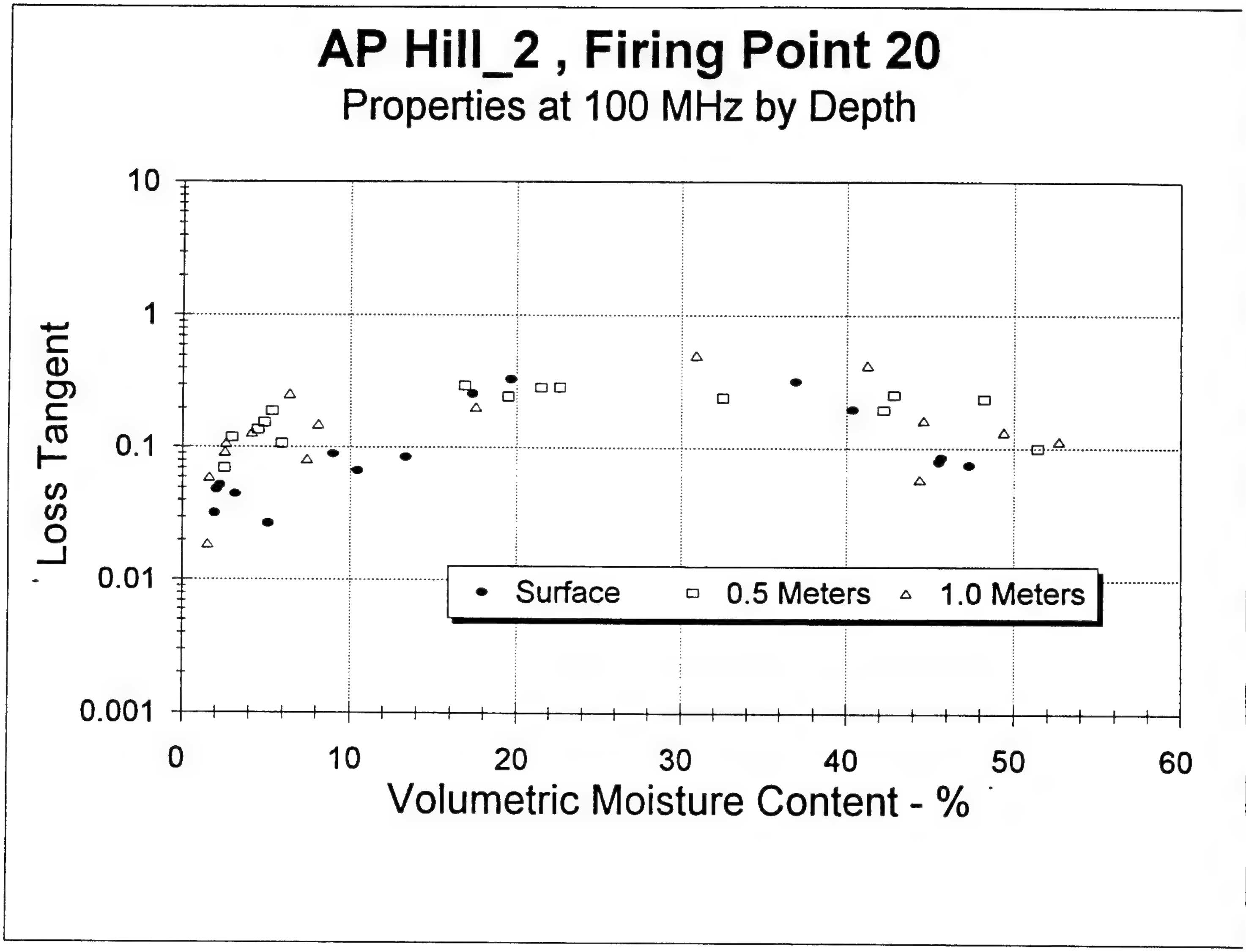
AP Hill_2
Properties at 100 MHz , All Depths
Firing Point 20
Firing Point 22
Normalized Phase Velocity
Volumetric Moisture Content - %
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
10
20
30
40
50
60

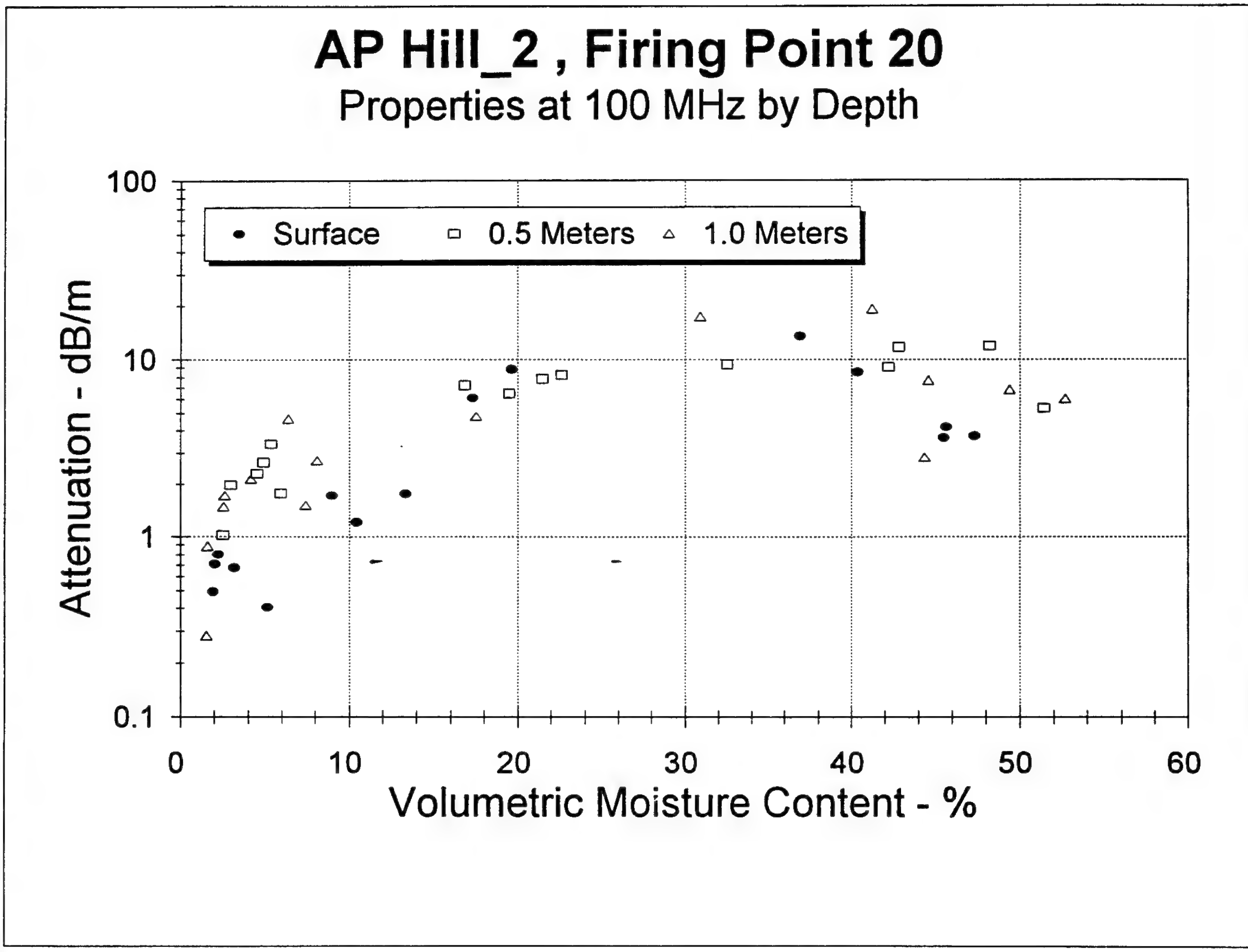

AP Hill_2 , Firing Point 20
Properties at 100 MHz by Depth
Surface
0.5 Meters
1.0 Meters
Re(Dielectric Constant)
Volumetric Moisture Content - %
0
10
20
30
40
50
60

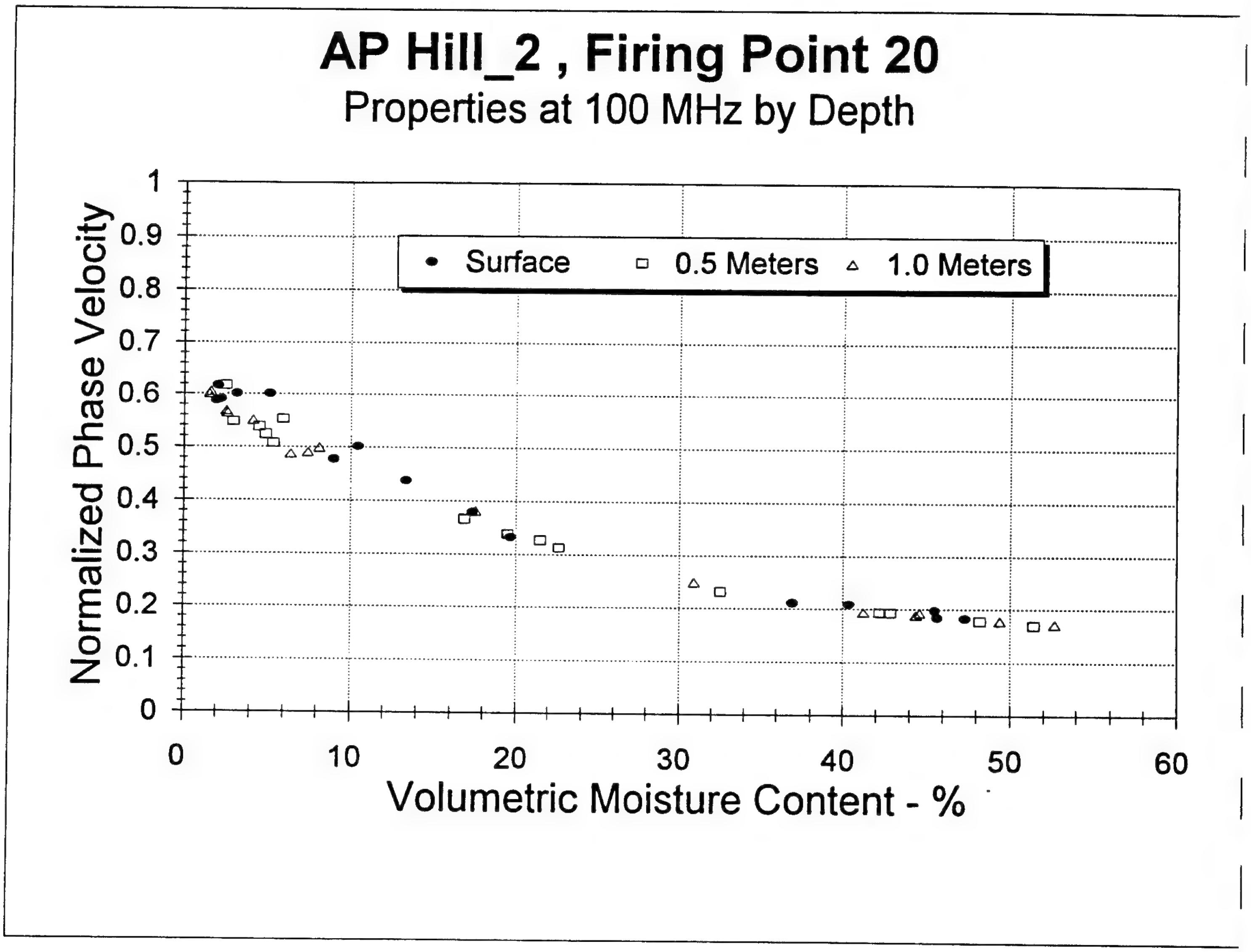

AP Hill_2 , Firing Point 20
Properties at 100 MHz by Depth
Surface
0.5 Meters
1.0 Meters
Im(Dielectric Constant)
Volumetric Moisture Content - %
0
10
20
30
40
50
60



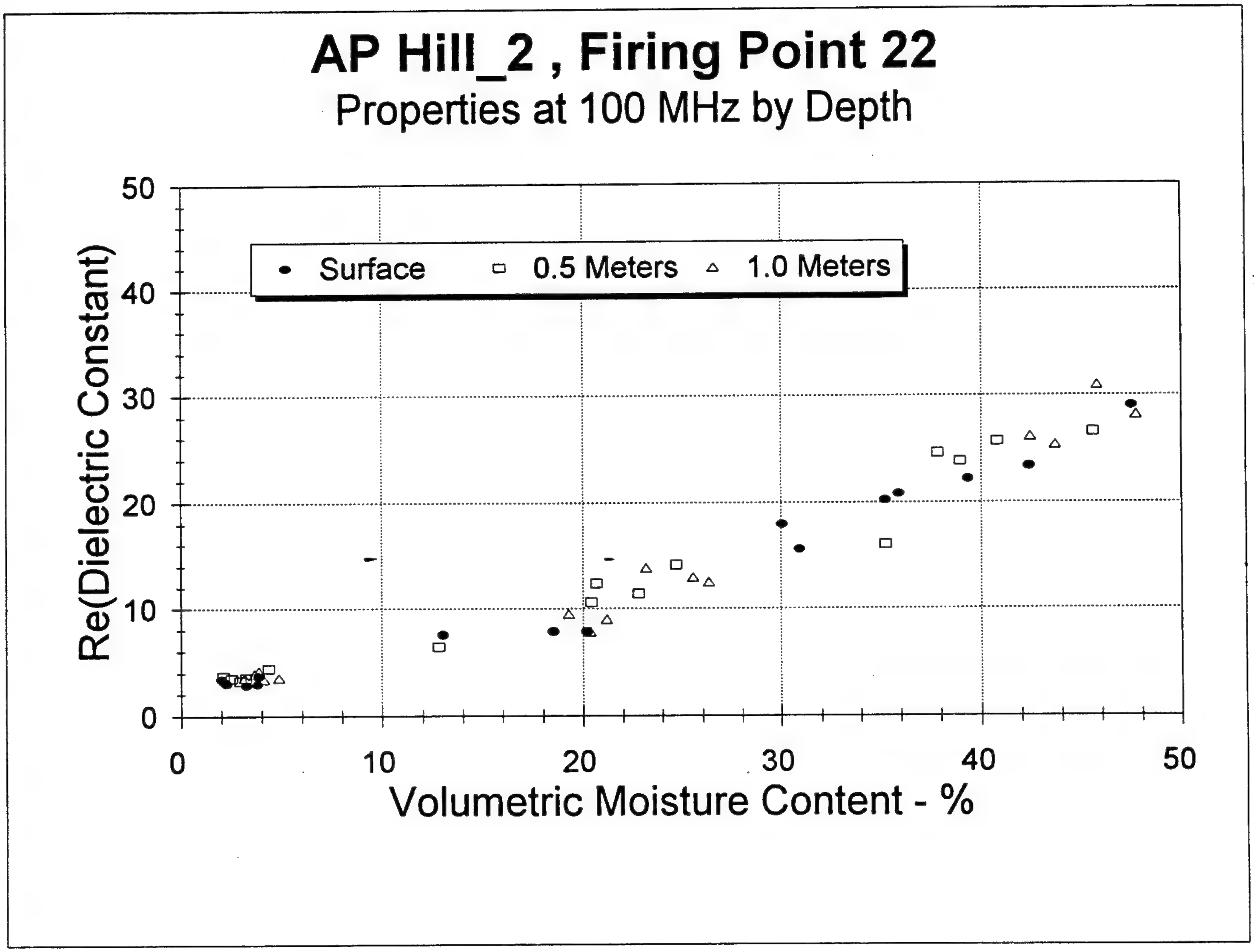
AP Hill_2 , Firing Point 20
Properties at 100 MHz by Depth
Surface
0.5 Meters
1.0 Meters
Conductivity - mho/m
1
0.1
0.01
0.001
0.0001
0
10
20
30
40
50
60
Volumetric Moisture Content - %


AP Hill_2 , Firing Point 20
Properties at 100 MHz by Depth
Loss Tangent
10
1
0.1
0.01
0.001
0
10
20
30
40
50
60
Volumetric Moisture Content - %
Surface
0.5 Meters
1.0 Meters

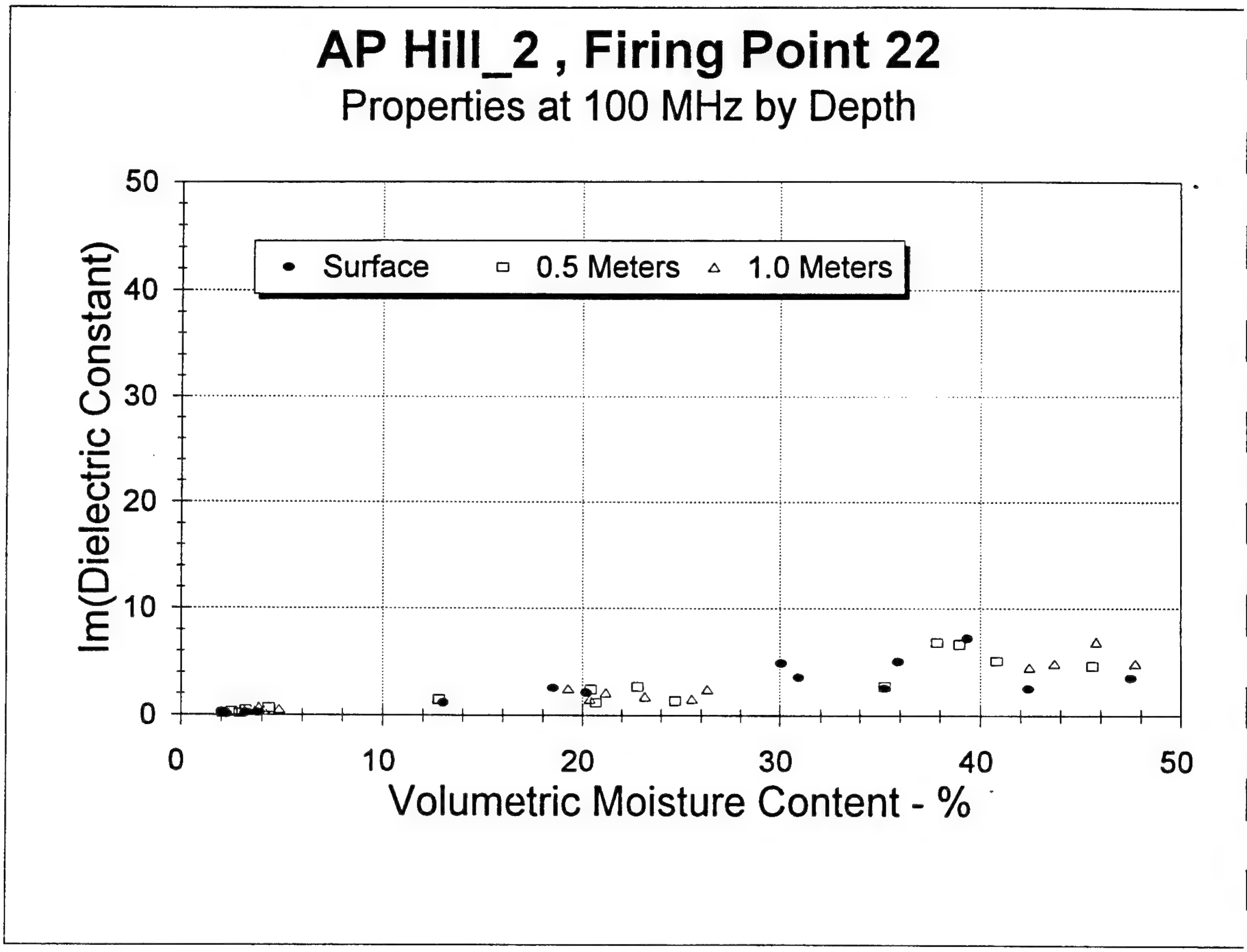

AP Hill_2 , Firing Point 20
Properties at 100 MHz by Depth
Surface
0.5 Meters
1.0 Meters
Attenuation - dB/m
100
10
1
0.1
0
10
20
30
40
50
60
Volumetric Moisture Content - %

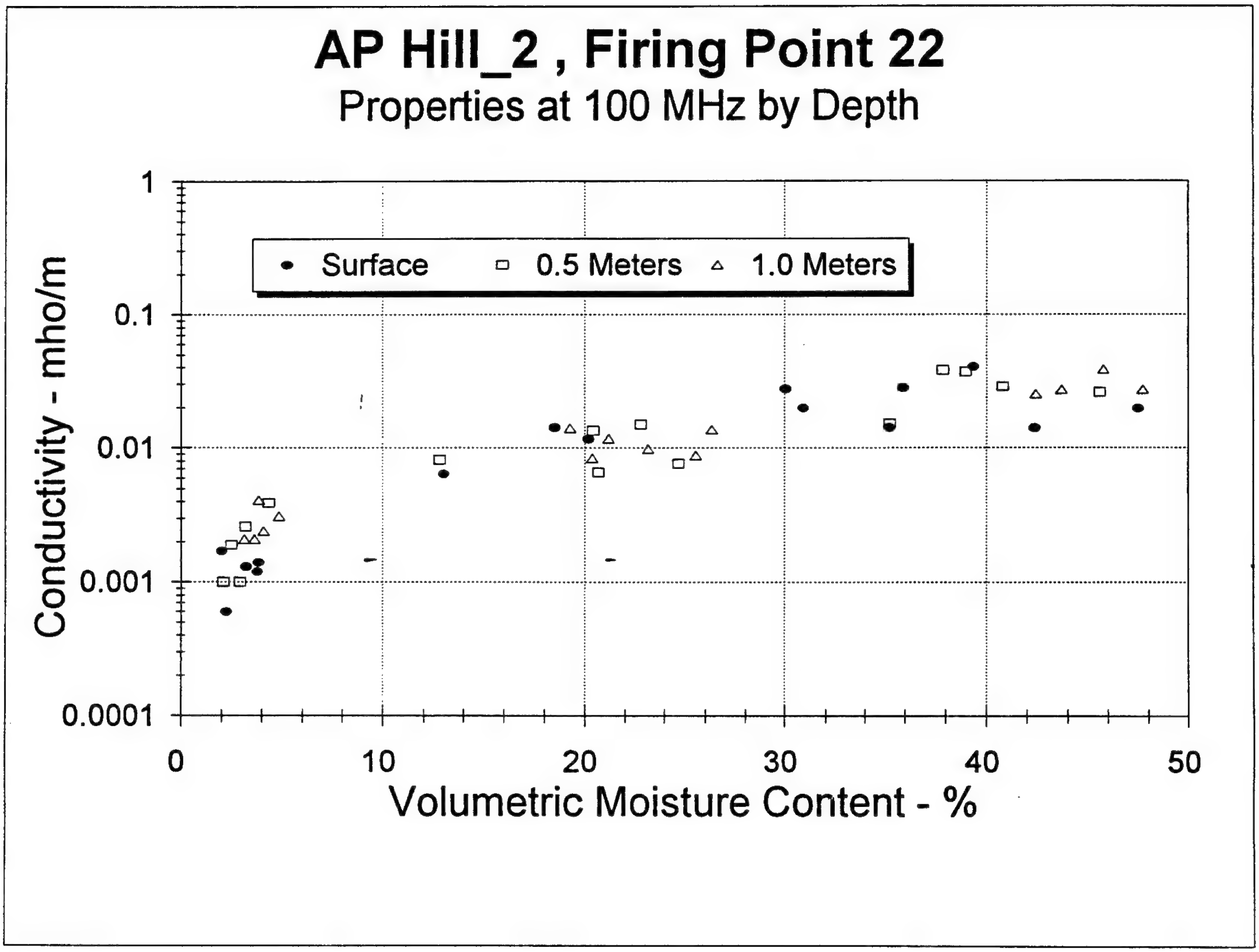


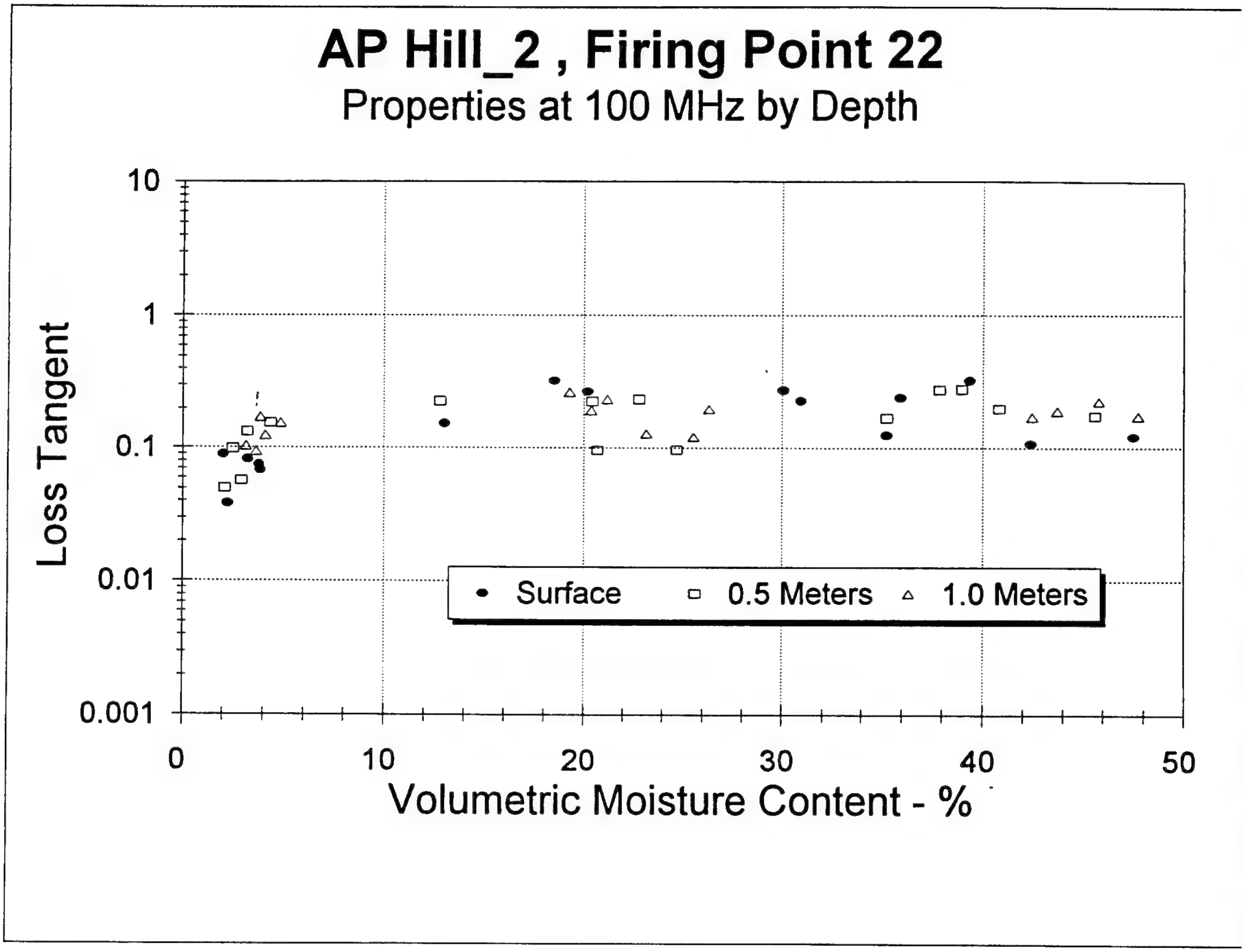
AP Hill_2 , Firing Point 20
Properties at 100 MHz by Depth
Surface
0.5 Meters
1.0 Meters
Normalized Phase Velocity
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
10
20
30
40
50
60
Volumetric Moisture Content - %

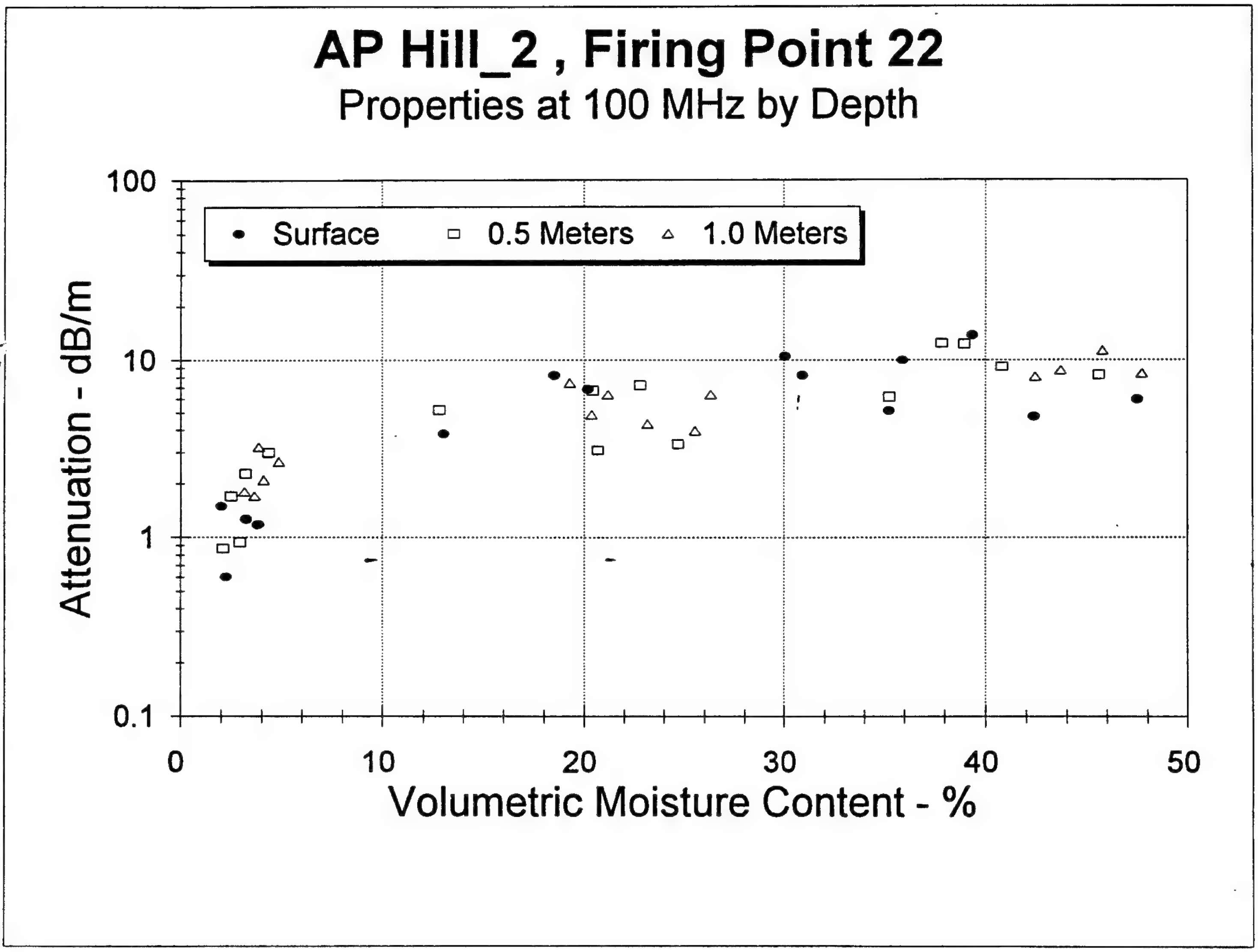


AP Hill_2 , Firing Point 22
Properties at 100 MHz by Depth
Surface
0.5 Meters
1.0 Meters
Re(Dielectric Constant)
Volumetric Moisture Content - %
0
10
20
30
40
50

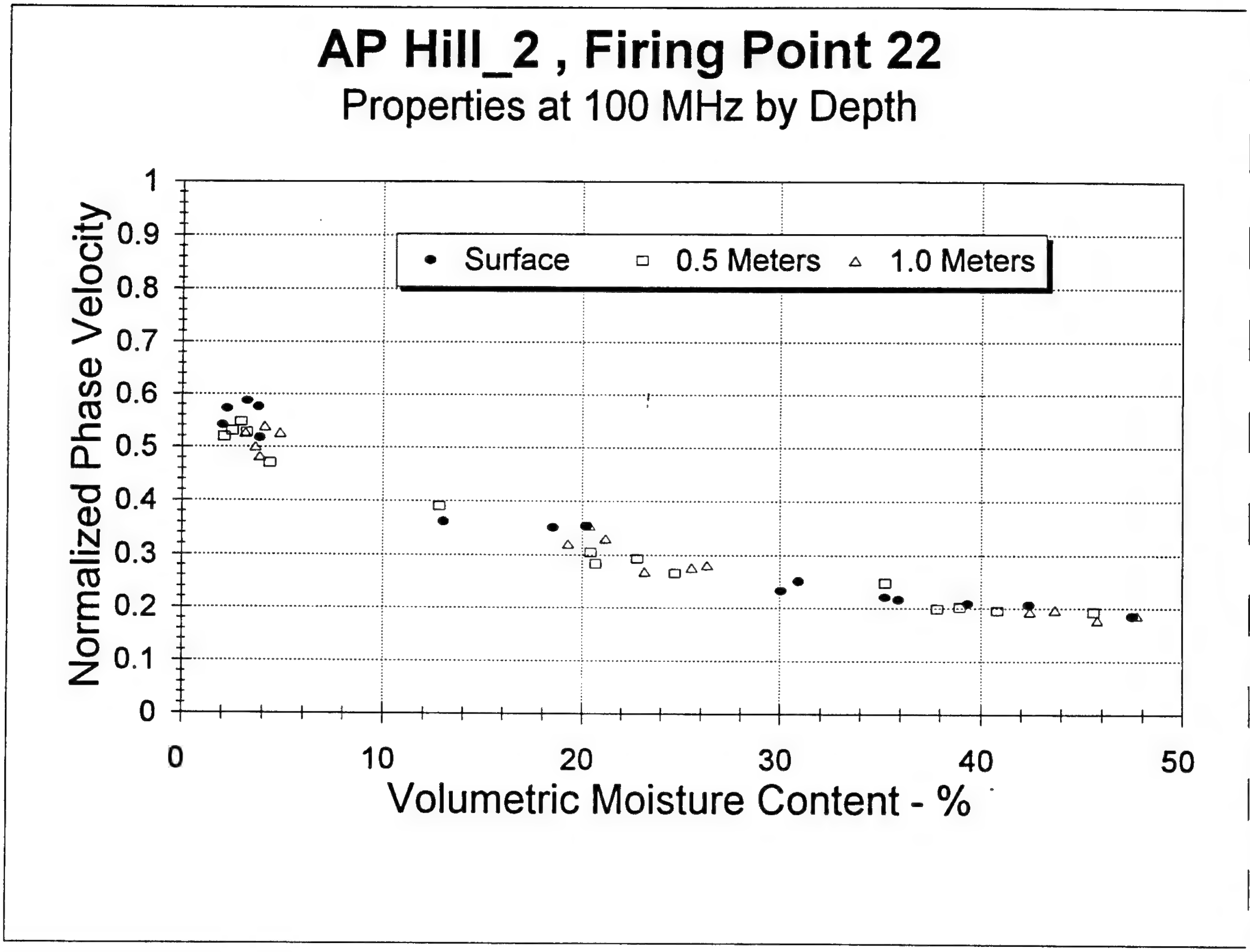

AP Hill_2 , Firing Point 22
Properties at 100 MHz by Depth
Surface
0.5 Meters
1.0 Meters
Im(Dielectric Constant)
Volumetric Moisture Content - %
0
10
20
30
40
50


AP Hill_2 , Firing Point 22
Properties at 100 MHz by Depth
Surface
0.5 Meters
1.0 Meters
Conductivity - mho/m
1
0.1
0.01
0.001
0.0001
0
10
20
30
40
50
Volumetric Moisture Content - %


AP Hill_2 , Firing Point 22
Properties at 100 MHz by Depth
10
1
0.1
0.01
0.001
Loss Tangent
0
10
20
30
40
50
Volumetric Moisture Content - %
Surface
0.5 Meters
1.0 Meters



AP Hill_2 , Firing Point 22
Properties at 100 MHz by Depth
Surface
0.5 Meters
1.0 Meters
Attenuation - dB/m
100
10
1
0.1
0
10
20
30
40
50
Volumetric Moisture Content - %


AP Hill_2 , Firing Point 22
Properties at 100 MHz by Depth
Normalized Phase Velocity
Volumetric Moisture Content - %
Surface
0.5 Meters
1.0 Meters
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
10
20
30
40
50

Fort A.P. Hill_2
Properties at 200 Mhz

Fort AP Hill_2 Soil Properties at 200 MHz

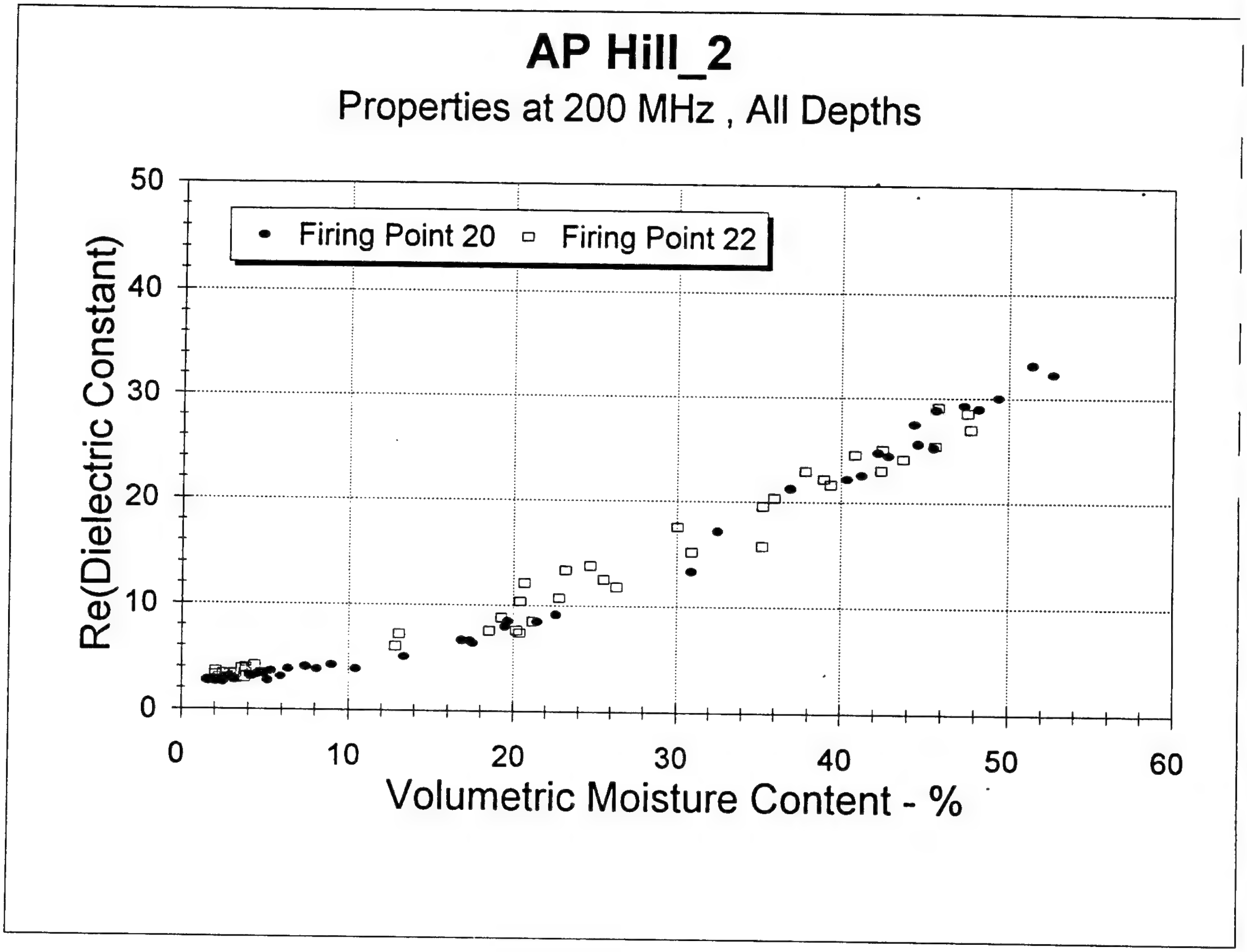
Firing Point 20

File Name	Vol Moist	Dry Dens g/cc	Re(eps)	Im(eps)	Cond mho/m	Loss Tan	Attn dB/m	Norm Vel
200_1b	2.57	1.40	2.96	0.24	0.003	0.08	2.49	0.58
200_1d	2.65	1.40	3.00	0.27	0.003	0.09	2.78	0.58
200_1w	49.42	1.40	30.08	3.00	0.033	0.10	9.94	0.18
200_2b	5.97	1.21	3.13	0.24	0.003	0.08	2.48	0.56
200_2d	2.52	1.21	2.55	0.14	0.002	0.05	1.57	0.63
200_2w	51.44	1.21	33.21	2.64	0.029	0.08	8.34	0.17
200_sb	9.01	1.39	4.24	0.29	0.003	0.07	2.53	0.49
200_sd	2.27	1.39	2.79	0.12	0.001	0.04	1.35	0.60
200_sw	47.36	1.39	29.34	1.88	0.021	0.06	6.31	0.18
20122_1b	30.94	1.53	13.36	4.80	0.053	0.36	23.51	0.27
20122_1d	6.41	1.53	3.83	0.79	0.009	0.21	7.28	0.51
20122_1w	41.25	1.53	22.56	6.88	0.077	0.31	26.06	0.21
20122_2b	16.89	1.37	6.68	1.43	0.016	0.21	10.03	0.38
20122_2d	2.98	1.37	3.17	0.32	0.004	0.10	3.28	0.56
20122_2w	48.22	1.37	28.98	4.80	0.053	0.17	16.17	0.19
20122_sb	17.37	1.47	6.65	1.04	0.012	0.16	7.29	0.39
20122_sd	3.19	1.47	2.77	0.10	0.001	0.04	1.08	0.60
20122_sw	40.39	1.47	22.22	2.73	0.030	0.12	10.53	0.21
20123_1b	8.11	1.33	3.82	0.41	0.005	0.11	3.84	0.51
20123_1d	1.61	1.33	2.69	0.14	0.002	0.05	1.54	0.61
20123_1w	52.69	1.33	32.32	2.60	0.029	0.08	8.30	0.18
20123_2b	21.49	1.66	8.49	1.75	0.020	0.21	10.89	0.34
20123_2d	4.55	1.66	3.33	0.35	0.004	0.11	3.53	0.55
20123_2w	32.55	1.66	17.16	2.98	0.033	0.17	13.06	0.24
20123_sb	19.71	1.54	8.52	1.66	0.018	0.19	10.28	0.34
20123_sd	1.95	1.54	2.87	0.08	0.001	0.03	0.86	0.59
20123_sw	36.96	1.54	21.30	3.88	0.043	0.18	15.22	0.22
2027_1b	7.44	1.53	4.04	0.24	0.003	0.06	2.18	0.50
2027_1d	1.54	1.53	2.74	0.06	0.001	0.02	0.61	0.60
2027_1w	44.38	1.53	27.49	1.43	0.016	0.05	4.96	0.19
2027_2b	22.63	1.53	9.19	1.94	0.022	0.21	11.55	0.33
2027_2d	5.34	1.53	3.61	0.55	0.006	0.15	5.25	0.53
2027_2w	42.86	1.53	24.45	4.38	0.049	0.18	16.06	0.20
2027_sb	10.49	1.44	3.87	0.19	0.002	0.05	1.72	0.51
2027_sd	5.16	1.44	2.72	0.05	0.001	0.02	0.60	0.61
2027_sw	45.55	1.44	25.25	1.42	0.016	0.06	5.13	0.20
2065_1b	17.55	1.47	6.43	0.94	0.011	0.15	6.73	0.39
2065_1d	4.15	1.47	3.12	0.31	0.004	0.10	3.22	0.57
2065_1w	44.58	1.47	25.59	2.93	0.033	0.11	10.53	0.20
2065_2b	19.52	1.48	7.98	1.44	0.016	0.18	9.21	0.35
2065_2d	4.91	1.48	3.40	0.43	0.005	0.13	4.21	0.54
2065_2w	42.22	1.48	24.77	3.53	0.039	0.14	12.86	0.20
2065_sb	13.39	1.37	5.11	0.30	0.003	0.06	2.38	0.44
2065_sd	2.09	1.37	2.61	0.09	0.001	0.04	1.06	0.62
2065_sw	45.70	1.37	28.87	1.61	0.018	0.06	5.44	0.19

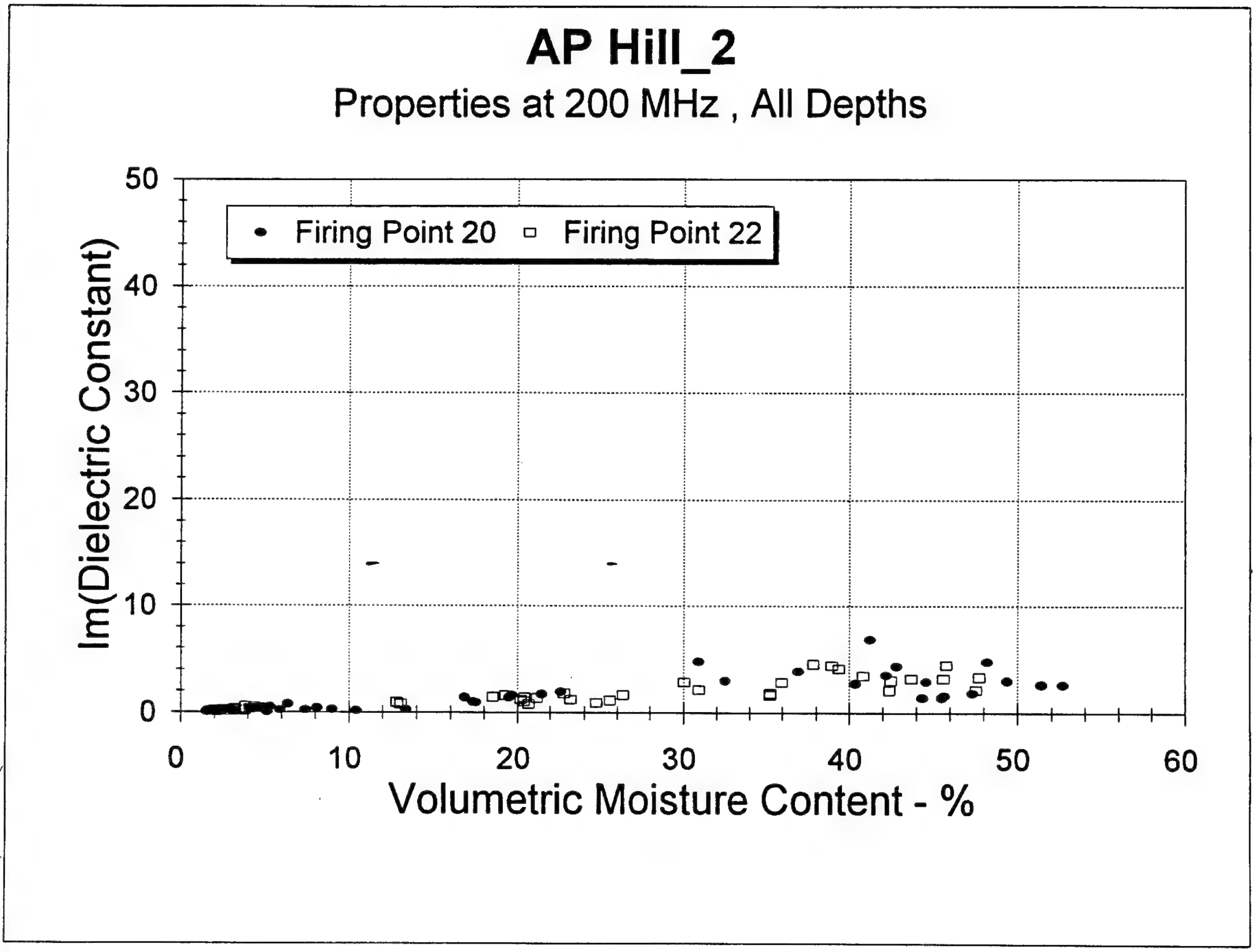
Fort AP Hill_2 Soil Properties at 200 MHz

Firing Point 22

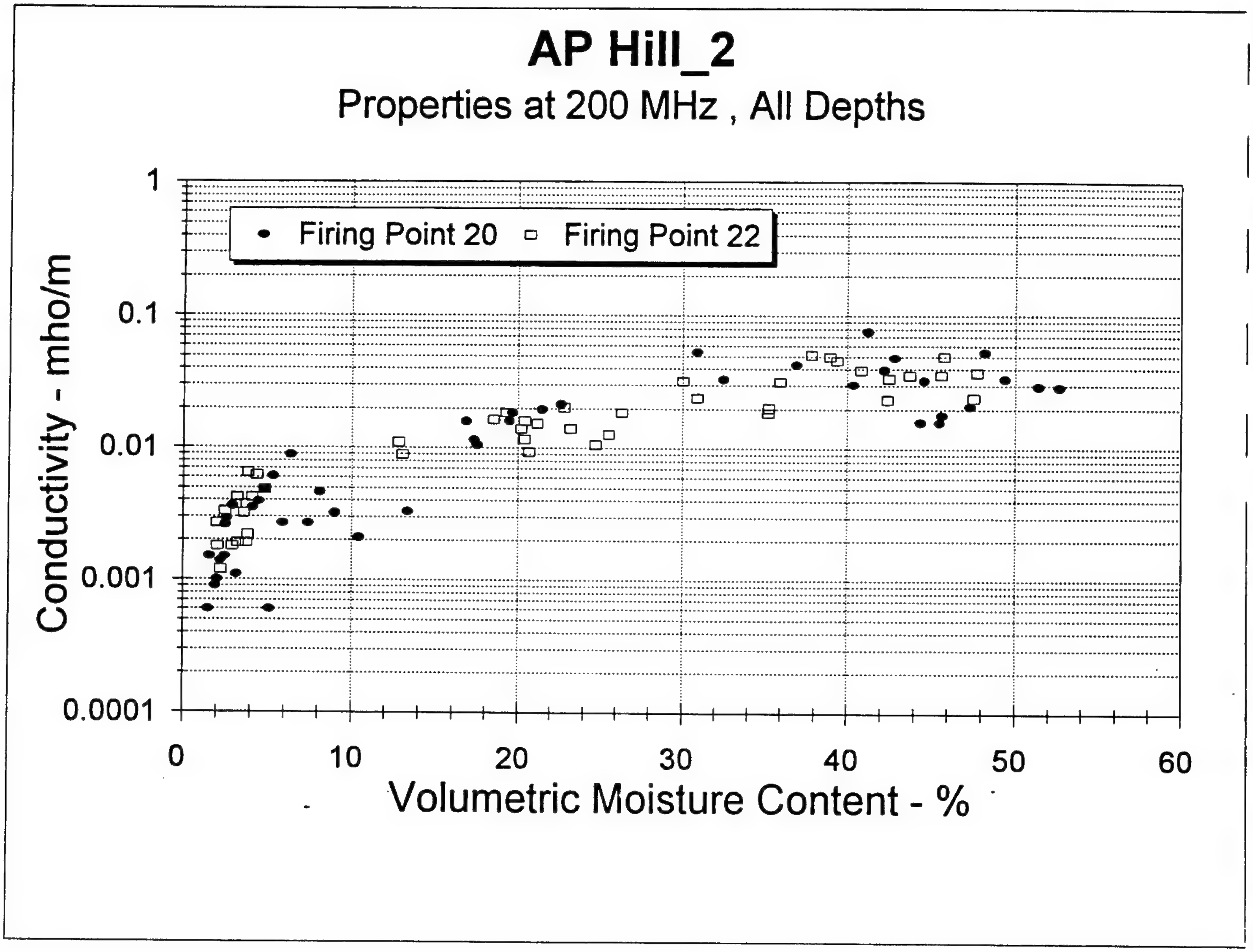
File Name	Vol Moist	Dry Dens g/cc	Re(eps)	Im(eps)	Cond mho/m	Loss Tan	Attn dB/m	Norm Vel
22122_1b	19.30	1.53	8.90	1.66	0.019	0.19	10.09	0.33
22122_1d	3.88	1.53	3.97	0.59	0.007	0.15	5.33	0.50
22122_1w	45.79	1.53	29.15	4.49	0.050	0.15	15.08	0.18
22122_2b	20.45	1.83	10.44	1.44	0.016	0.14	8.11	0.31
22122_2d	2.94	1.83	3.30	0.16	0.002	0.05	1.58	0.55
22122_2w	35.24	1.83	15.80	1.68	0.019	0.11	7.66	0.25
22122_sb	13.05	1.69	7.25	0.80	0.009	0.11	5.43	0.37
22122_sd	2.04	1.69	3.29	0.24	0.003	0.07	2.43	0.55
22122_sw	35.25	1.69	19.58	1.82	0.020	0.09	7.46	0.23
22123_1b	21.20	1.53	8.51	1.38	0.015	0.16	8.57	0.34
22123_1d	4.87	1.53	3.46	0.43	0.005	0.12	4.18	0.54
22123_1w	43.69	1.53	24.12	3.22	0.036	0.13	11.89	0.20
22123_2b	12.82	1.51	6.06	1.00	0.011	0.17	7.37	0.40
22123_2d	3.22	1.51	3.42	0.37	0.004	0.11	3.67	0.54
22123_2w	45.59	1.51	25.44	3.24	0.036	0.13	11.66	0.20
22123_sb	18.55	1.55	7.61	1.47	0.016	0.19	9.66	0.36
22123_sd	3.80	1.55	3.00	0.17	0.002	0.06	1.77	0.58
22123_sw	39.36	1.55	21.67	4.14	0.046	0.19	16.12	0.21
2227_1b	26.33	1.51	11.88	1.68	0.019	0.14	8.83	0.29
2227_1d	3.15	1.51	3.42	0.33	0.004	0.10	3.26	0.54
2227_1w	42.47	1.51	25.08	3.03	0.034	0.12	10.99	0.20
2227_2b	37.85	1.66	22.97	4.59	0.051	0.20	17.35	0.21
2227_2d	4.37	1.66	4.19	0.56	0.006	0.13	4.94	0.49
2227_2w	38.96	1.66	22.20	4.45	0.050	0.20	17.10	0.21
2227_sb	47.54	1.31	28.57	2.19	0.024	0.08	7.43	0.19
2227_sd	2.27	1.31	3.00	0.11	0.001	0.04	1.17	0.58
2227_sw	42.39	1.31	23.05	2.12	0.024	0.09	8.01	0.21
222_1b	20.41	1.40	7.43	1.06	0.012	0.14	7.03	0.37
222_1d	4.12	1.40	3.27	0.38	0.004	0.12	3.79	0.55
222_1w	47.74	1.40	27.01	3.37	0.037	0.12	11.76	0.19
222_2b	22.82	1.57	10.77	1.81	0.020	0.17	10.01	0.30
222_2d	2.51	1.57	3.38	0.30	0.003	0.09	2.96	0.54
222_2w	40.82	1.57	24.56	3.50	0.039	0.14	12.82	0.20
222_sb	20.23	1.55	7.65	1.26	0.014	0.16	8.24	0.36
222_sd	3.26	1.55	2.89	0.17	0.002	0.06	1.79	0.59
222_sw	35.92	1.55	20.38	2.87	0.032	0.14	11.55	0.22
2265_1b	23.21	1.99	13.39	1.27	0.014	0.09	6.29	0.27
2265_1d	3.65	1.99	3.89	0.29	0.003	0.07	2.65	0.51
2265_1w	25.57	1.99	12.59	1.14	0.013	0.09	5.86	0.28
2265_2b	20.71	1.94	12.17	0.83	0.009	0.07	4.33	0.29
2265_2d	2.09	1.94	3.62	0.16	0.002	0.04	1.51	0.53
2265_2w	24.72	1.94	13.85	0.95	0.011	0.07	4.66	0.27
2265_sb	30.08	1.82	17.56	2.89	0.032	0.16	12.51	0.24
2265_sd	3.87	1.82	3.66	0.19	0.002	0.05	1.85	0.52
2265_sw	30.94	1.82	15.21	2.16	0.024	0.14	10.04	0.26



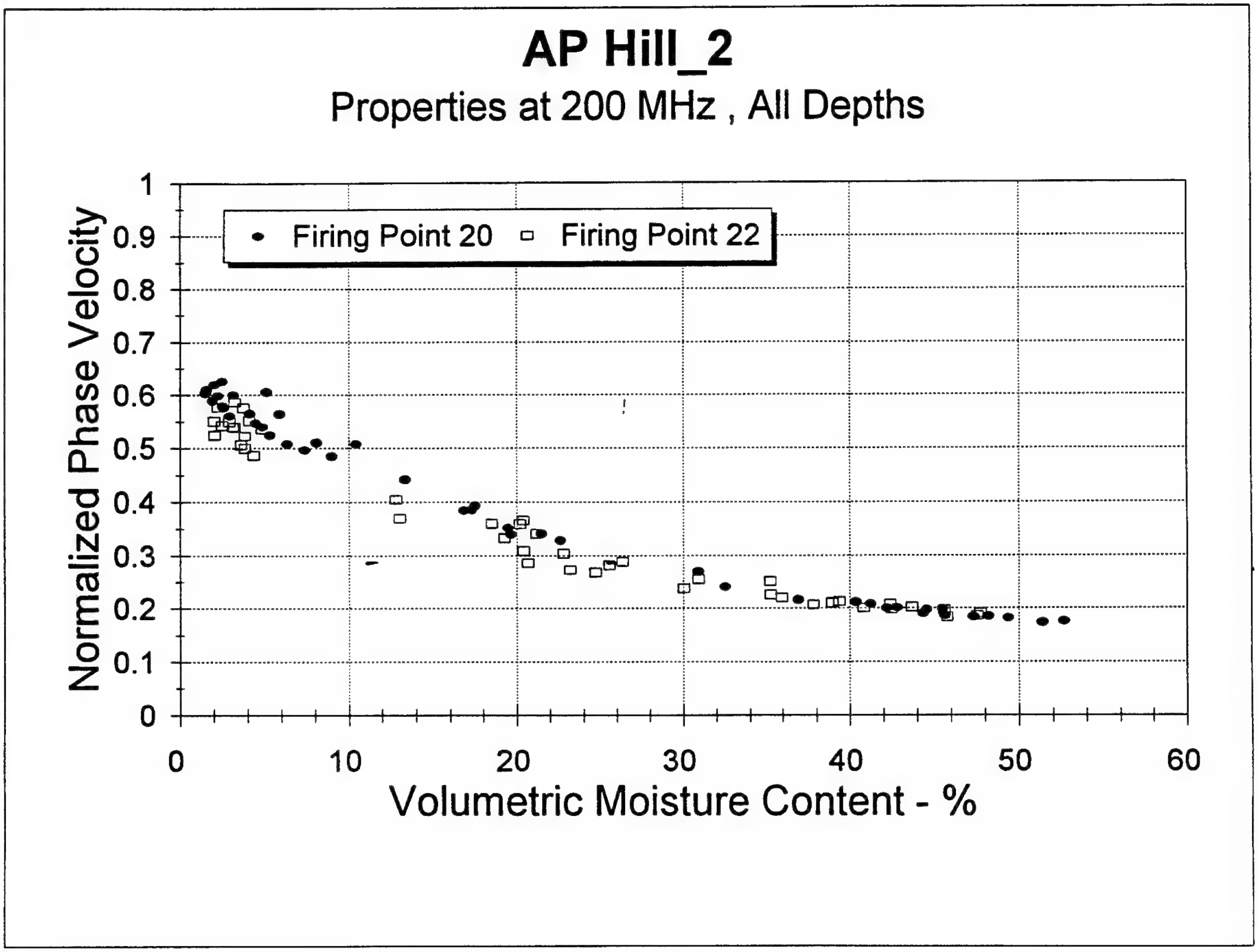
AP Hill_2
Properties at 200 MHz , All Depths
Firing Point 20
Firing Point 22
Re(Dielectric Constant)
Volumetric Moisture Content - %
0
10
20
30
40
50
60

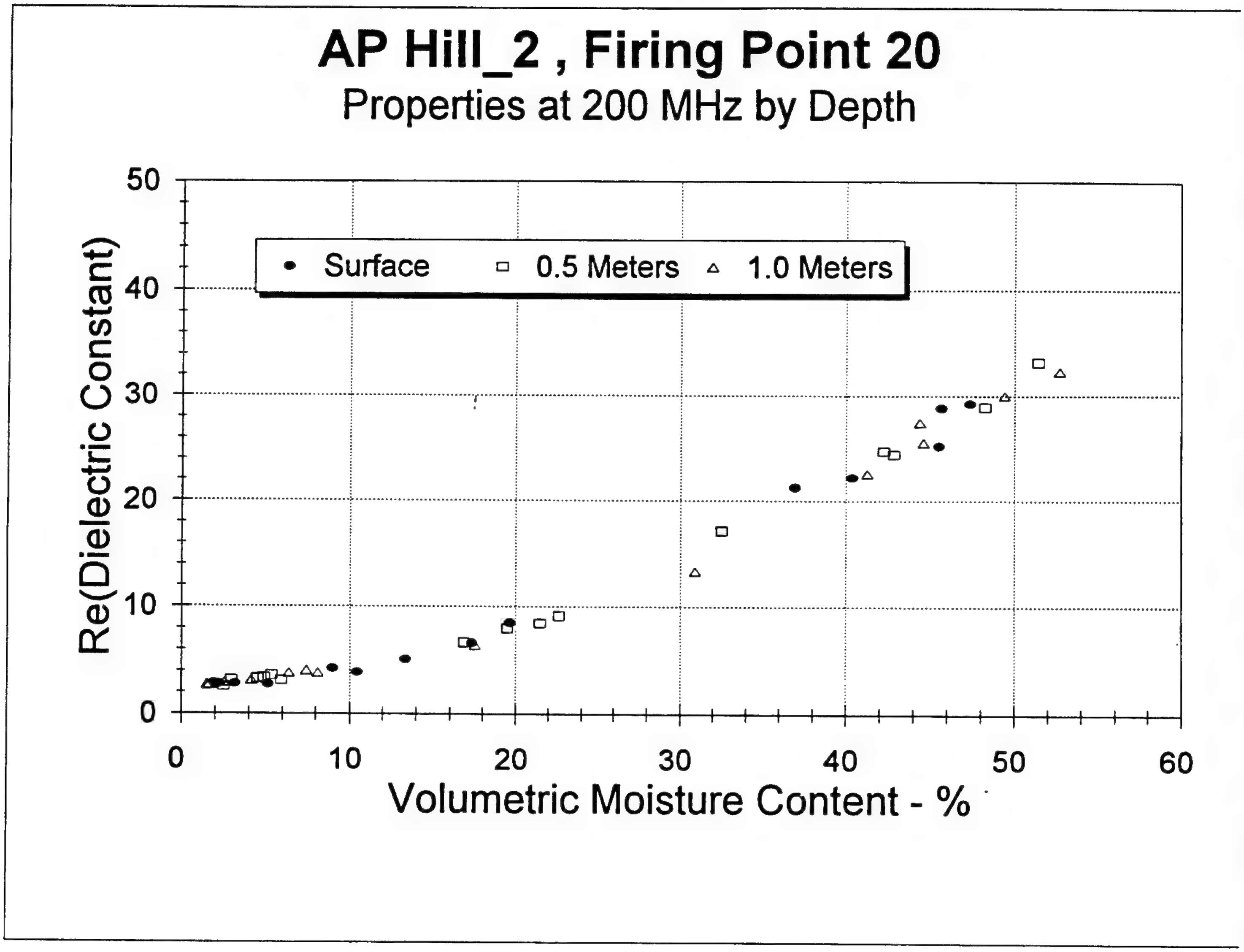


AP Hill_2
Properties at 200 MHz , All Depths
Firing Point 20
Firing Point 22
Im(Dielectric Constant)
50
40
30
20
10
0
0
10
20
30
40
50
60
Volumetric Moisture Content - %

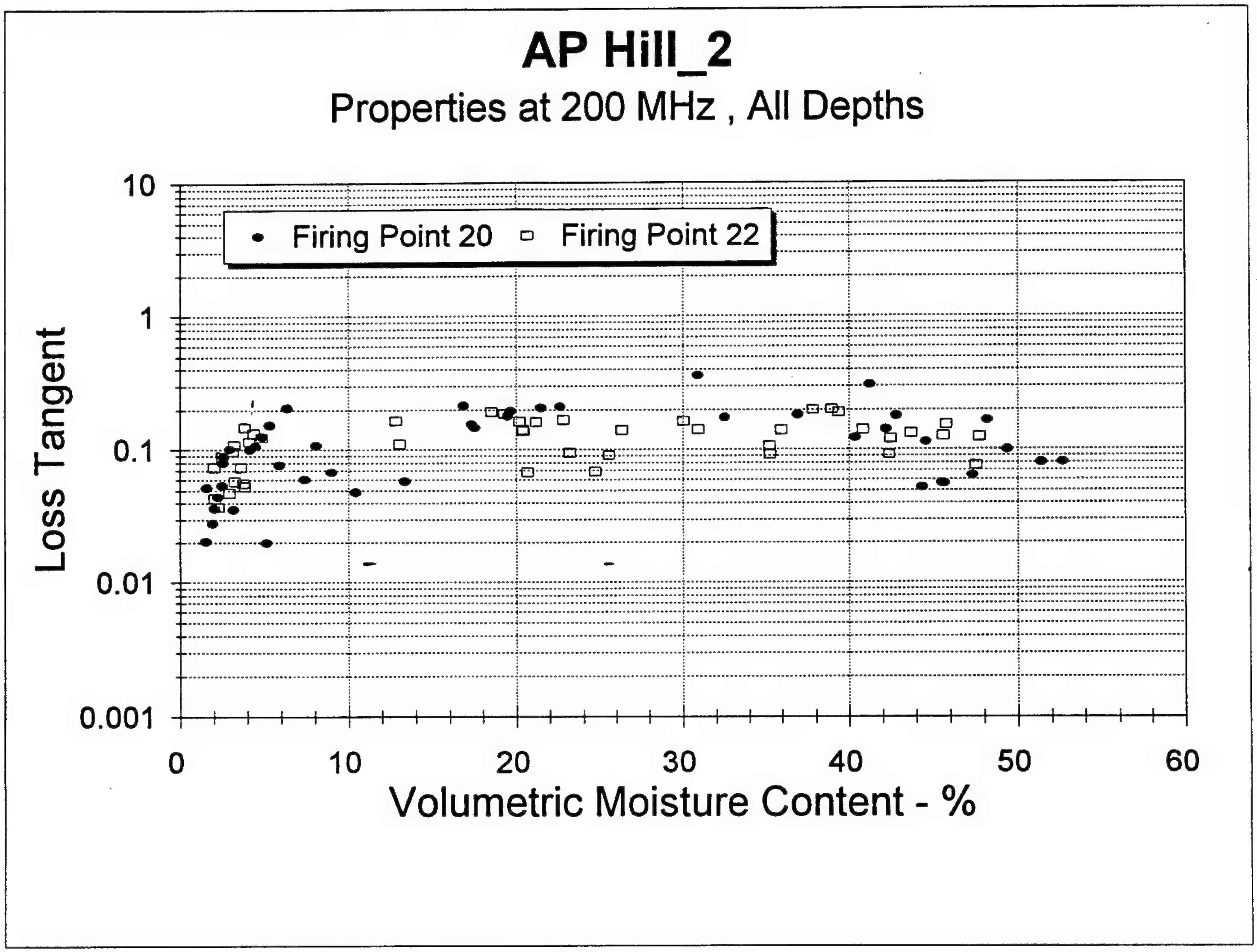


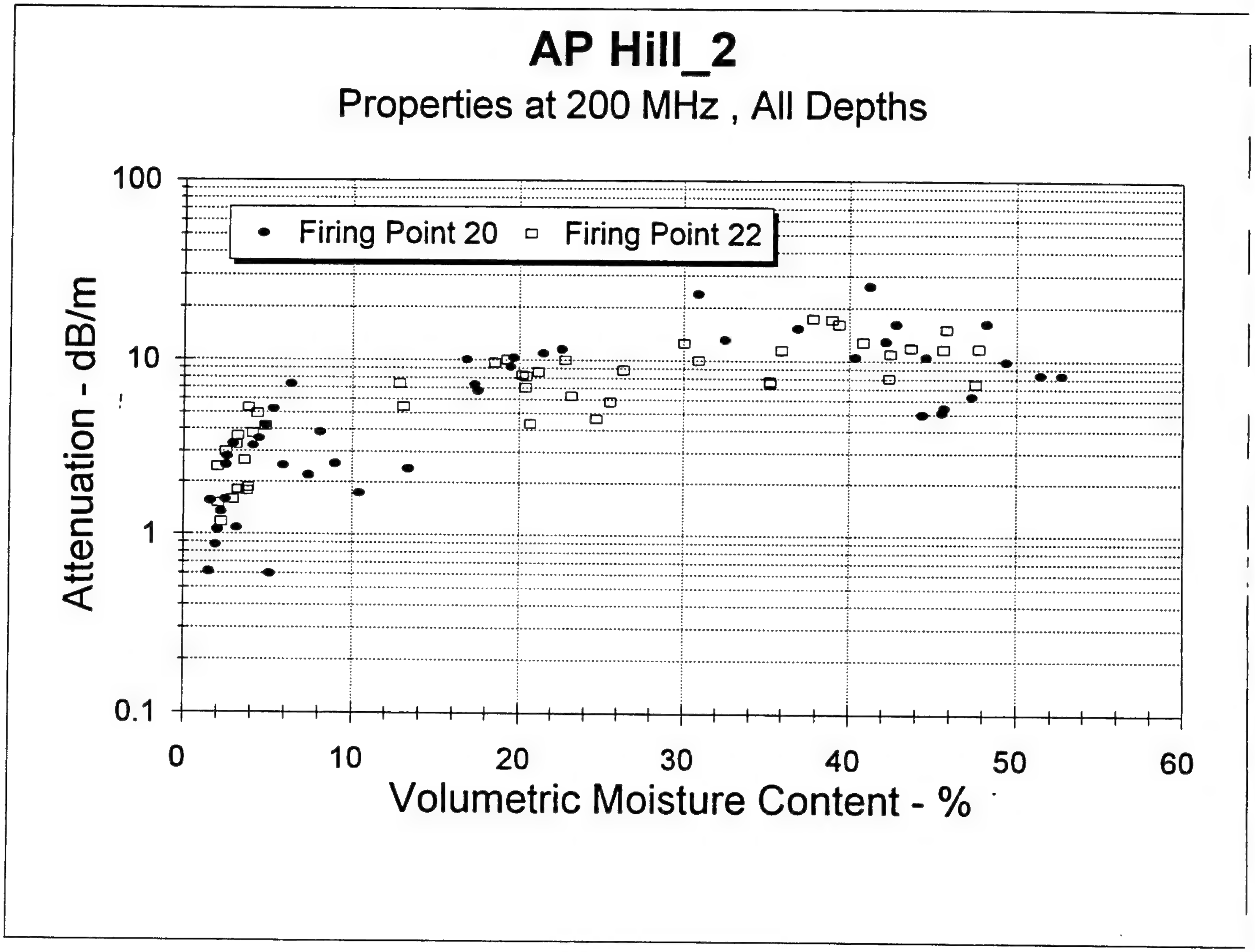
AP Hill_2
Properties at 200 MHz , All Depths
Firing Point 20
Firing Point 22
Conductivity - mho/m
1
0.1
0.01
0.001
0.0001
0
10
20
30
40
50
60
Volumetric Moisture Content - %


AP Hill_2
Properties at 200 MHz , All Depths
Firing Point 20
Firing Point 22
Normalized Phase Velocity
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
10
20
30
40
50
60
Volumetric Moisture Content - %

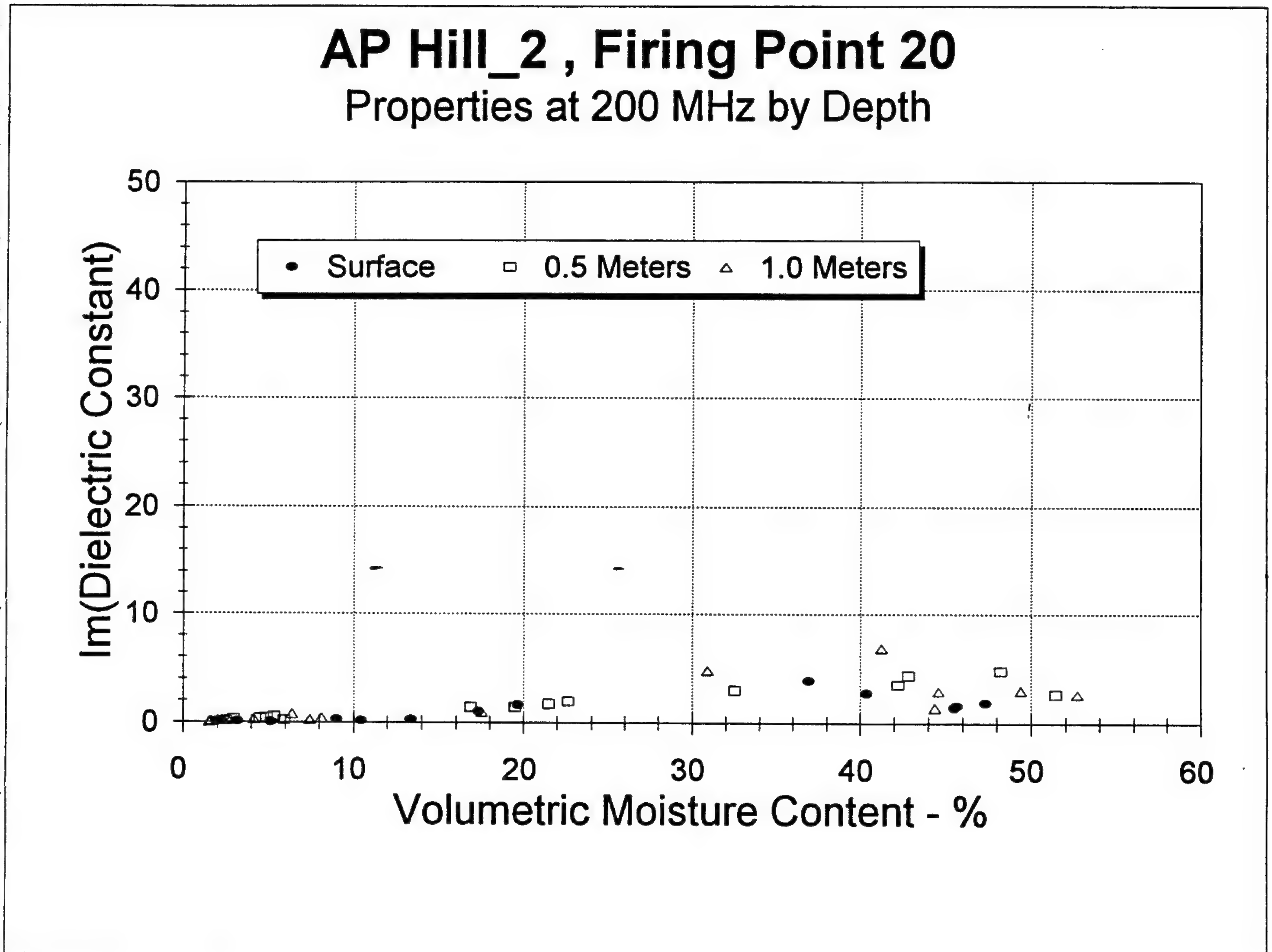


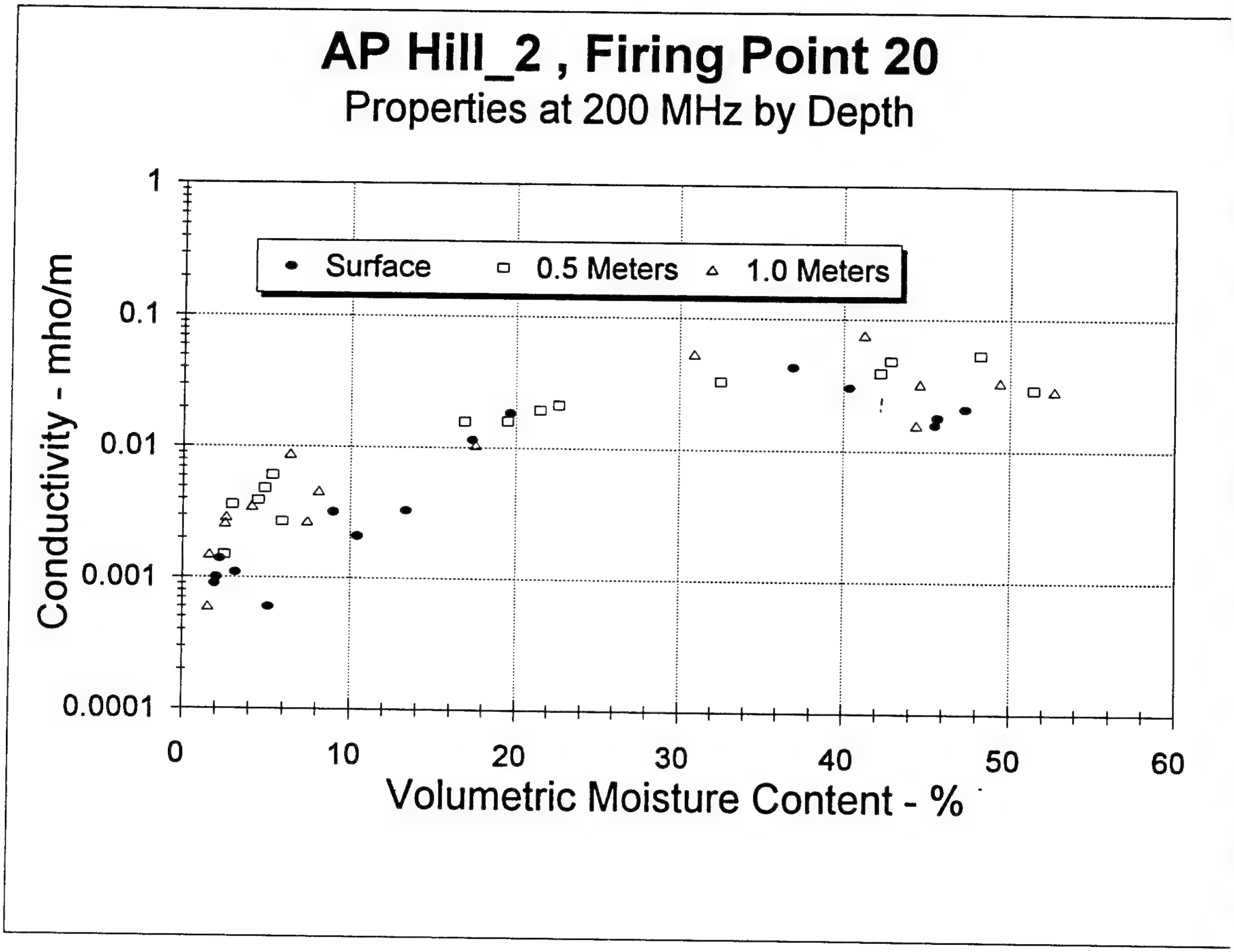
AP Hill_2 , Firing Point 20
Properties at 200 MHz by Depth
Surface
0.5 Meters
1.0 Meters
Re(Dielectric Constant)
Volumetric Moisture Content - %
0
10
20
30
40
50
60


AP Hill_2
Properties at 200 MHz , All Depths
Firing Point 20
Firing Point 22
Loss Tangent
10
1
0.1
0.01
0.001
0
10
20
30
40
50
60
Volumetric Moisture Content - %

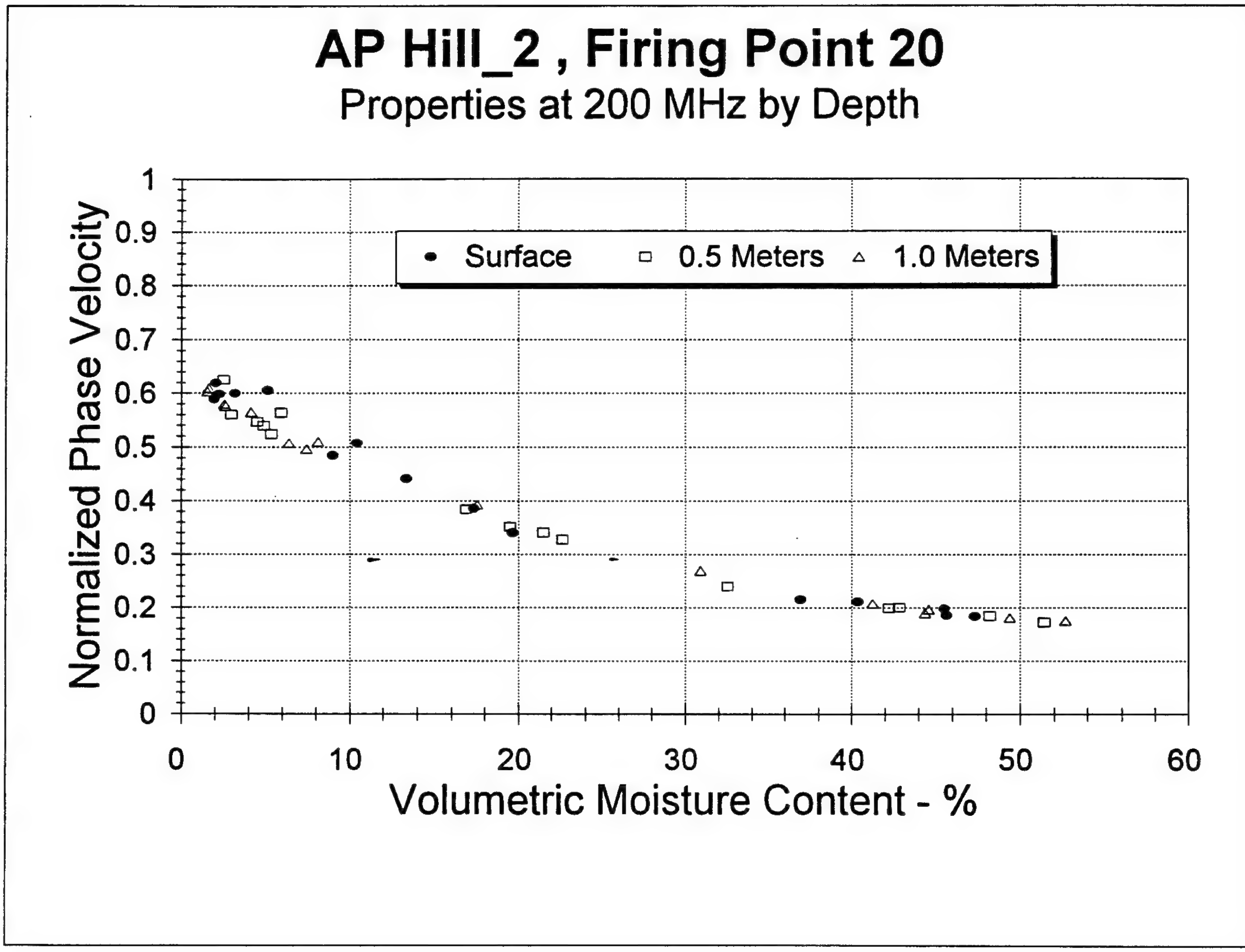


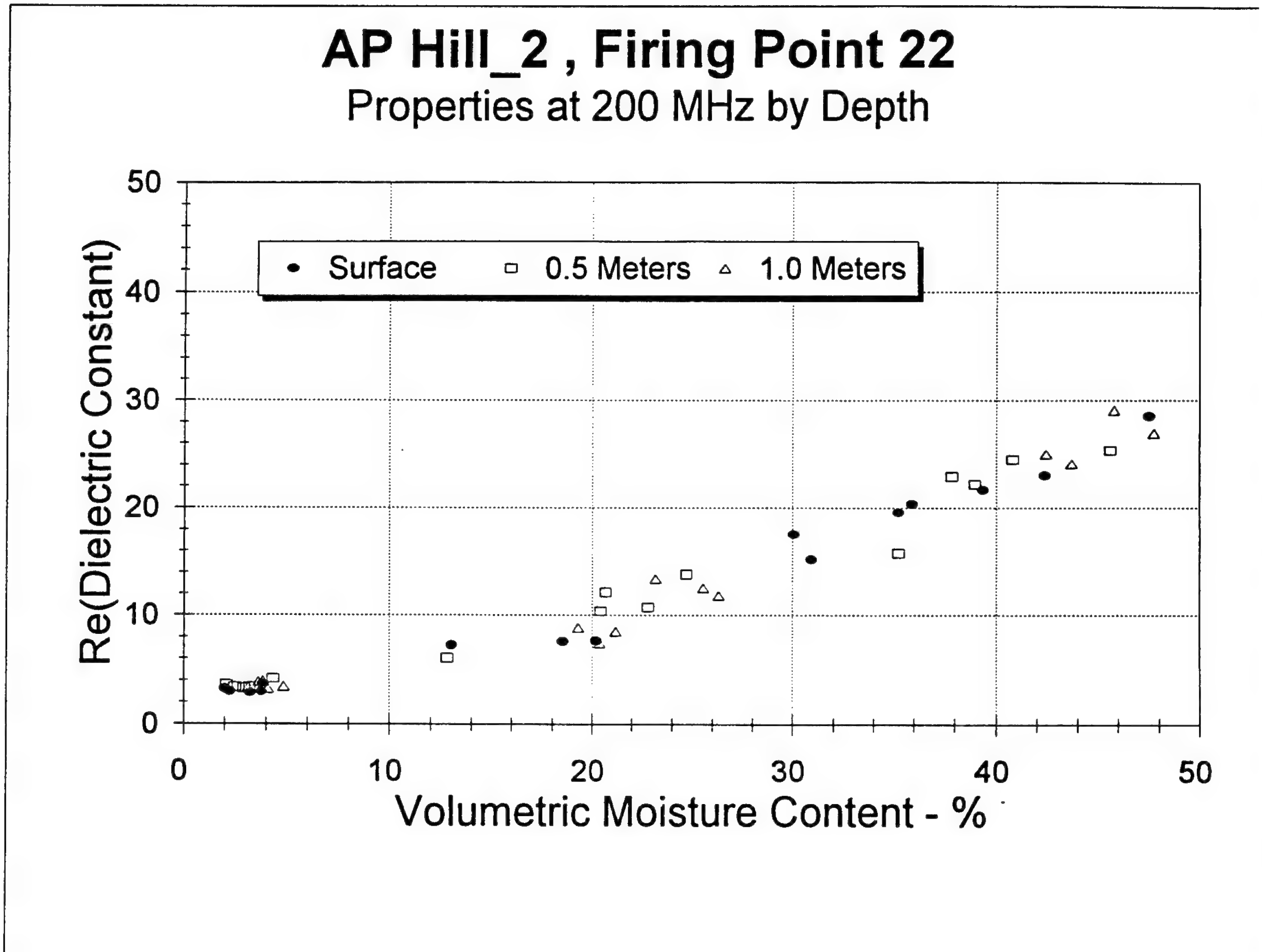
AP Hill_2
Properties at 200 MHz , All Depths
Firing Point 20
Firing Point 22
Attenuation - dB/m
100
10
1
0.1
0
10
20
30
40
50
60
Volumetric Moisture Content - %

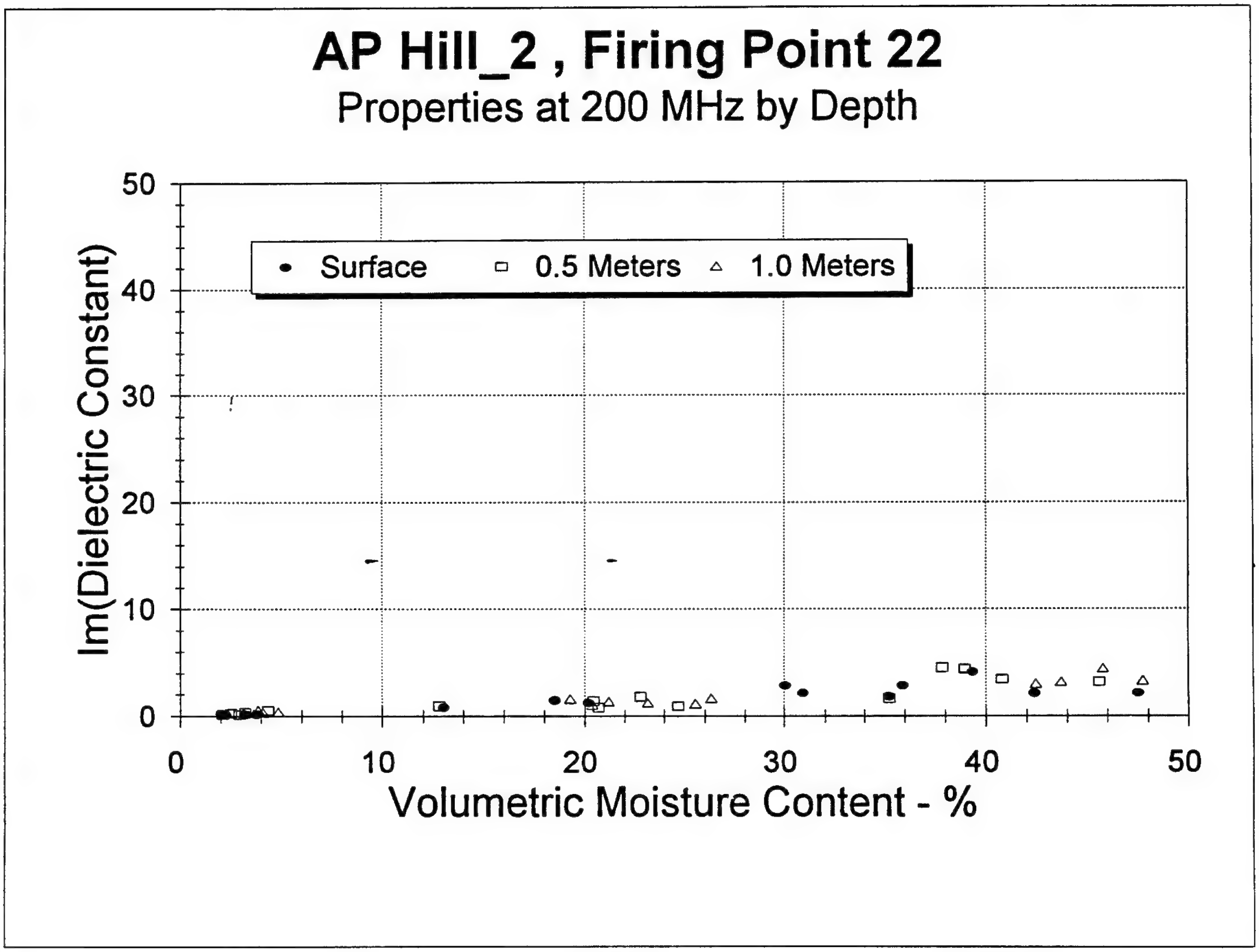

AP Hill_2 , Firing Point 20
Properties at 200 MHz by Depth
Surface
0.5 Meters
1.0 Meters
Im(Dielectric Constant)
0
10
20
30
40
50
0
10
20
30
40
50
60
Volumetric Moisture Content - %



AP Hill_2 , Firing Point 20
Properties at 200 MHz by Depth
Surface
0.5 Meters
1.0 Meters
Conductivity - mho/m
1
0.1
0.01
0.001
0.0001
0
10
20
30
40
50
60
Volumetric Moisture Content - %


AP Hill_2 , Firing Point 20
Properties at 200 MHz by Depth
Normalized Phase Velocity
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Surface
0.5 Meters
1.0 Meters
0
10
20
30
40
50
60
Volumetric Moisture Content - %

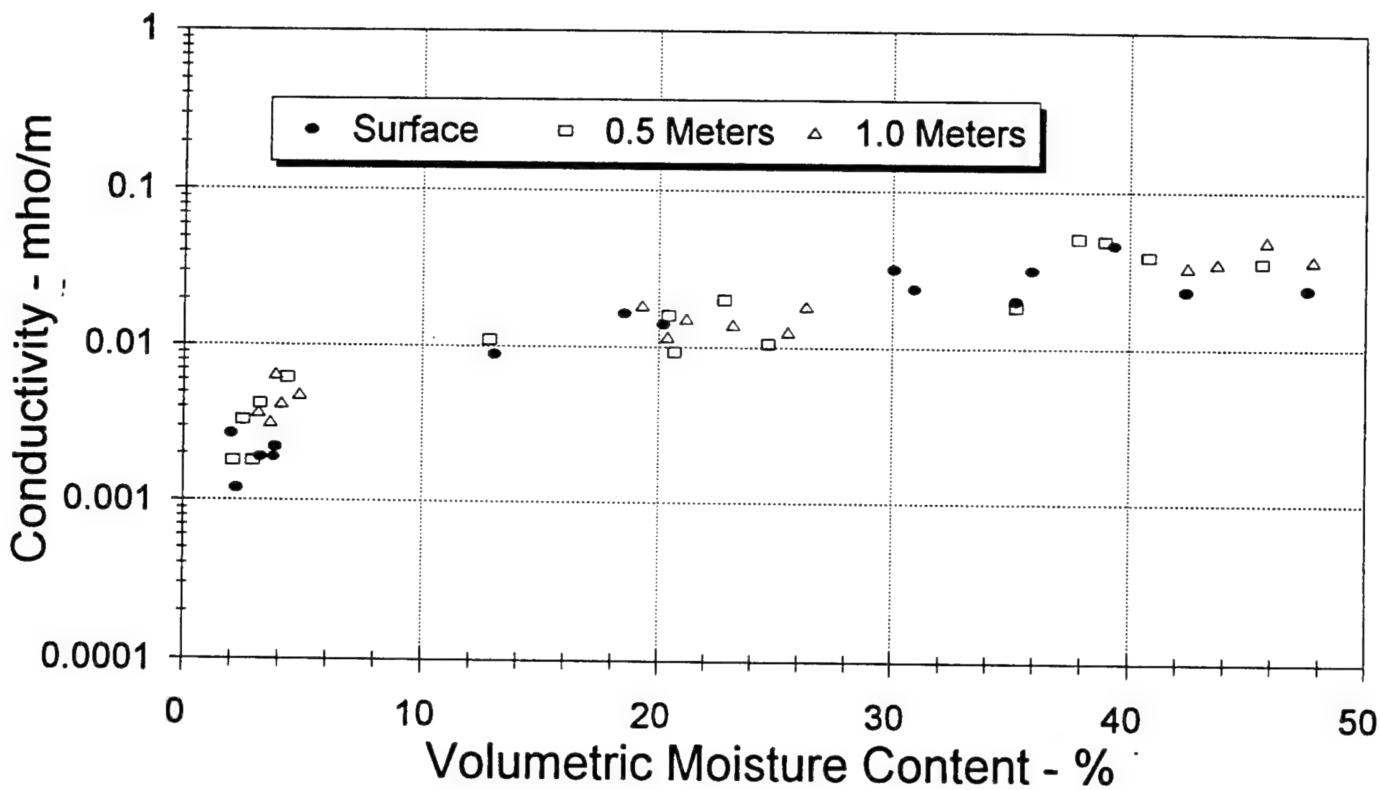

AP Hill_2 , Firing Point 22
Properties at 200 MHz by Depth
Surface
0.5 Meters
1.0 Meters
Re(Dielectric Constant)
Volumetric Moisture Content - %
0
10
20
30
40
50

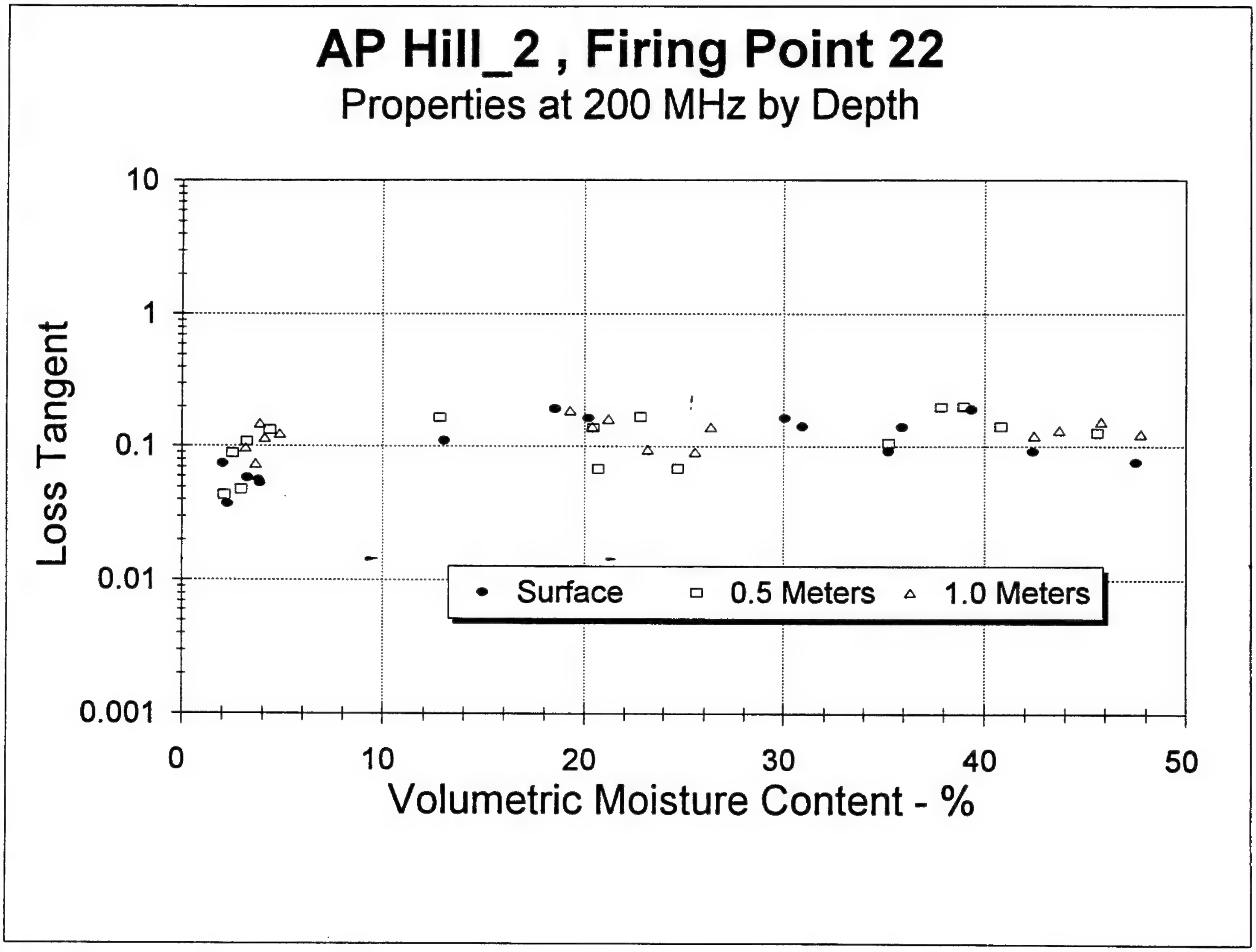


AP Hill_2 , Firing Point 22
Properties at 200 MHz by Depth
Surface
0.5 Meters
1.0 Meters
Im(Dielectric Constant)
0
10
20
30
40
50
Volumetric Moisture Content - %

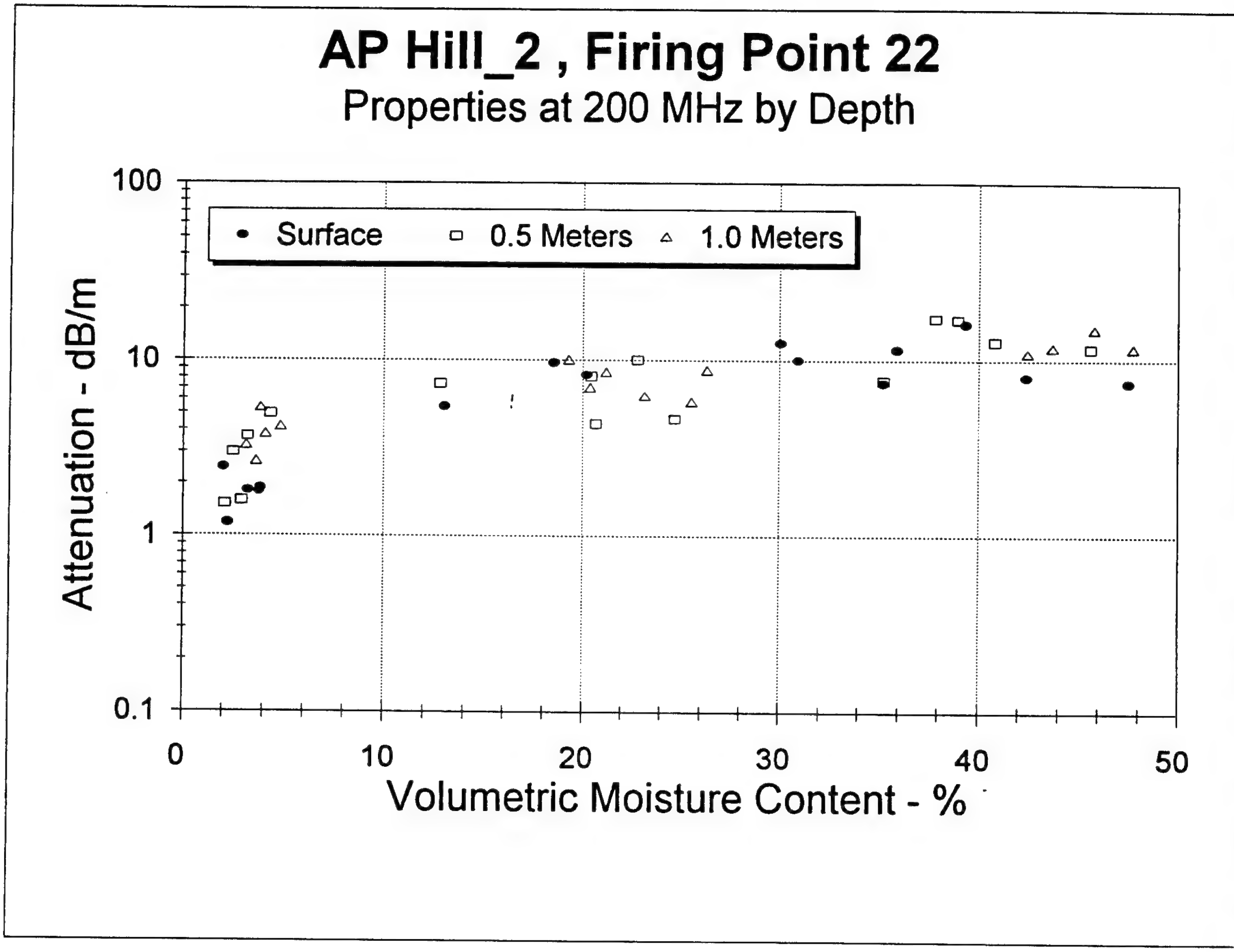
AP Hill_2 , Firing Point 22

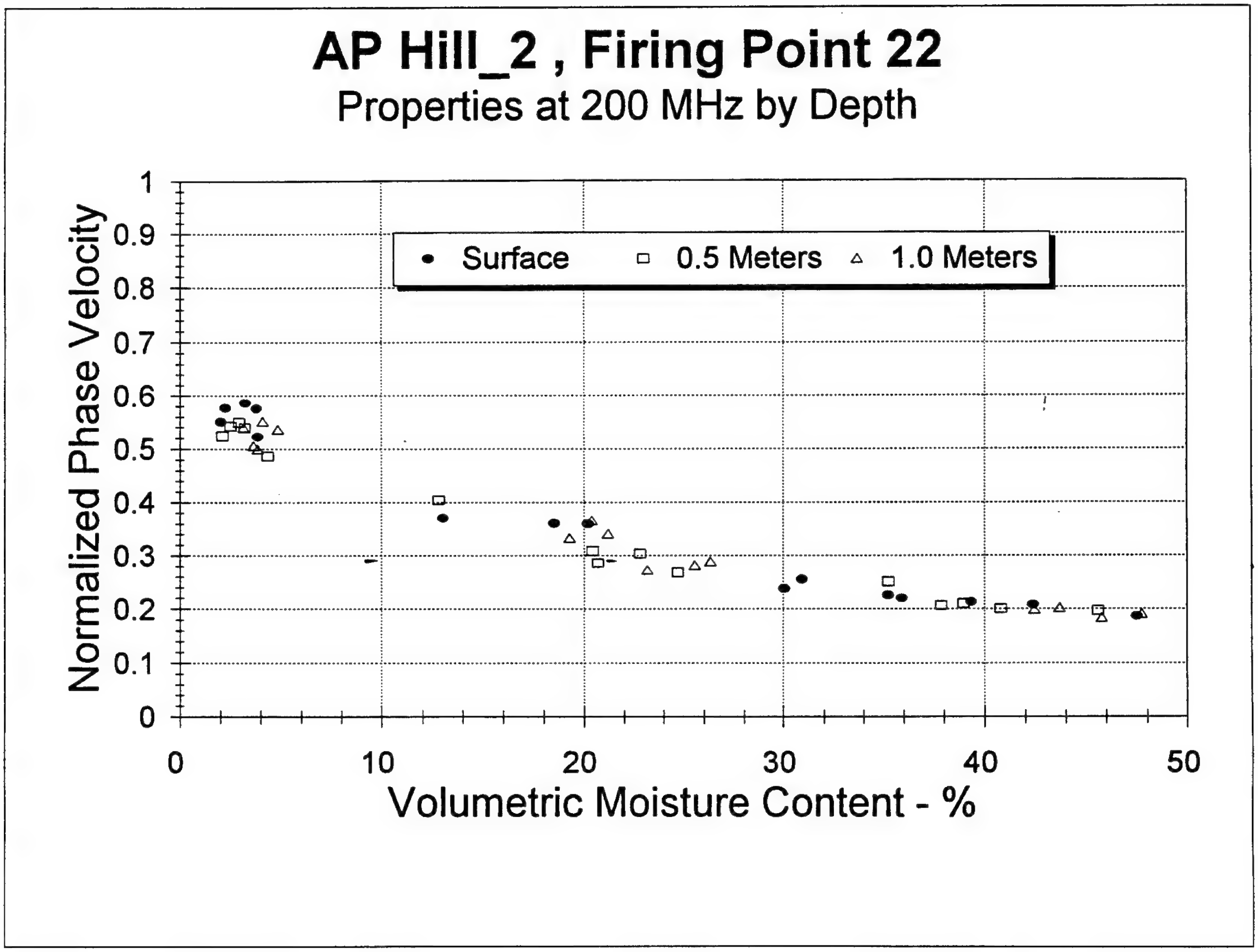
Properties at 200 MHz by Depth





AP Hill_2 , Firing Point 22
Properties at 200 MHz by Depth
Loss Tangent
10
1
0.1
0.01
0.001
0
10
20
30
40
50
Volumetric Moisture Content - %
Surface
0.5 Meters
1.0 Meters


AP Hill_2 , Firing Point 22
Properties at 200 MHz by Depth
Surface
0.5 Meters
1.0 Meters
Attenuation - dB/m
100
10
1
0.1
0
10
20
30
40
50
Volumetric Moisture Content - %


AP Hill_2 , Firing Point 22
Properties at 200 MHz by Depth
Surface
0.5 Meters
1.0 Meters
Normalized Phase Velocity
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
10
20
30
40
50
Volumetric Moisture Content - %

Fort A.P. Hill_2
Properties at 895 Mhz

Fort AP Hill_2 Soil Properties at 895 MHz

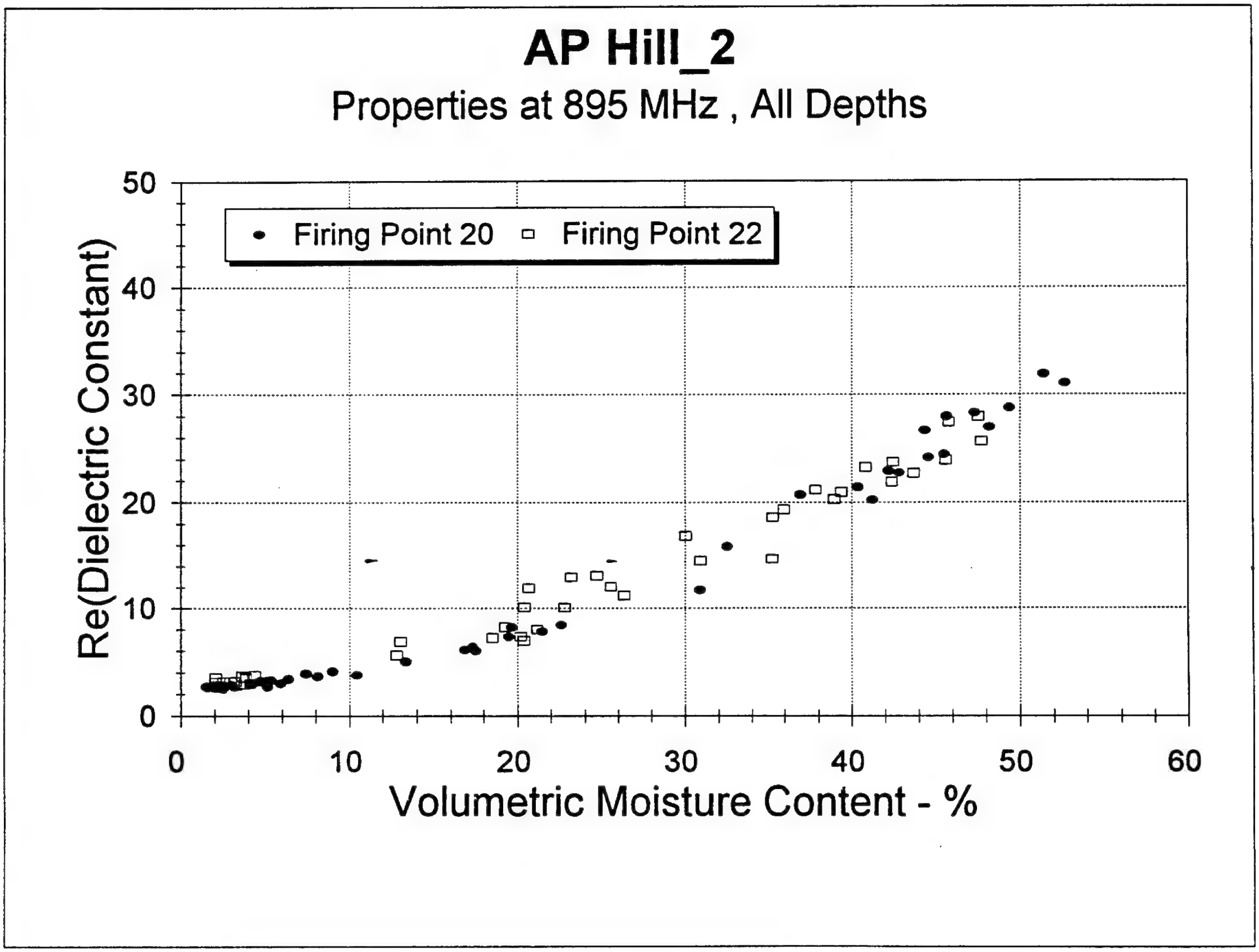
Firing Point 20

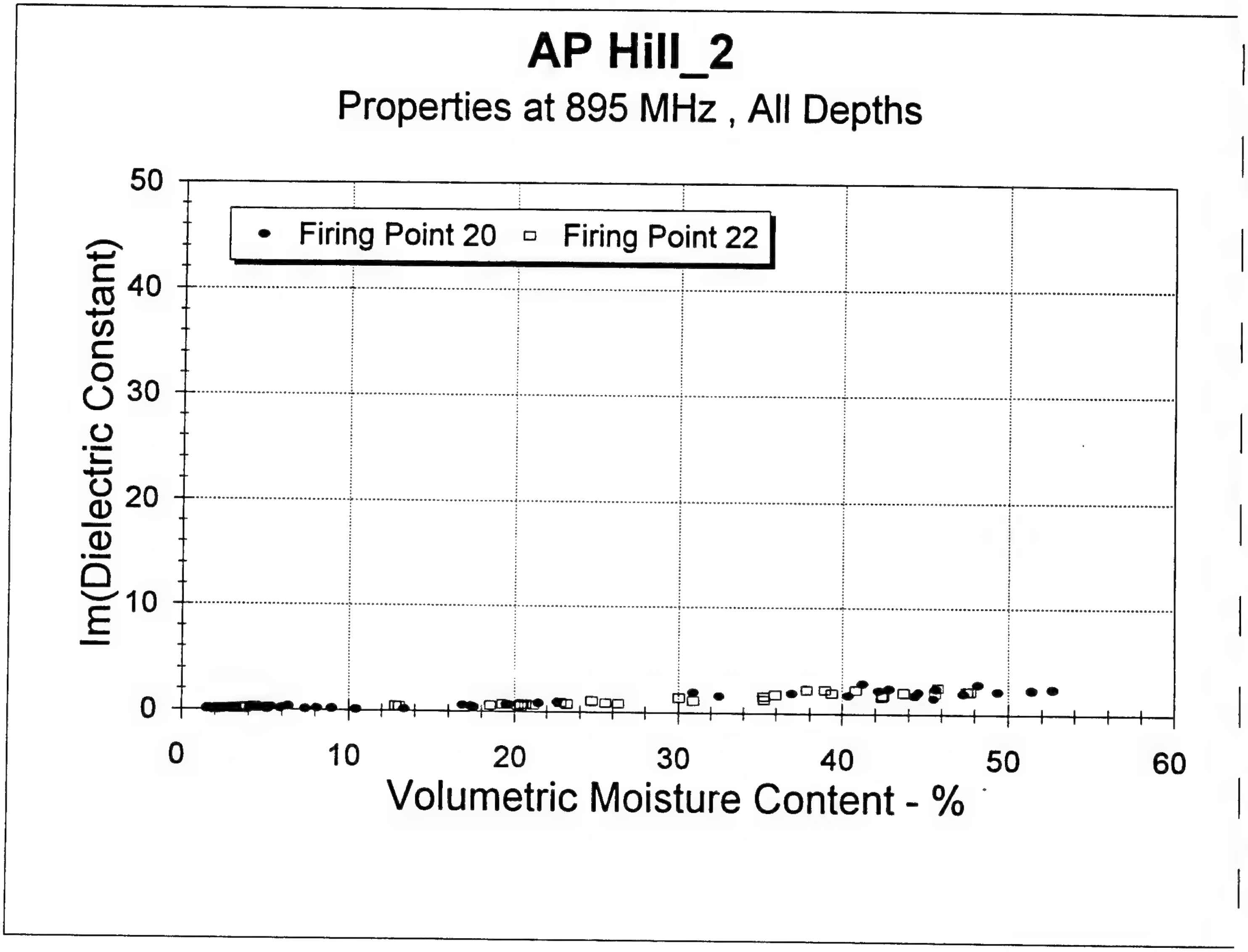
File Name	Vol Moist	Dry Dens g/cc	Re(eps)	Im(eps)	Cond mho/m	Loss Tan	Attn dB/m	Norm Vel
200_1b	2.57	1.40	2.79	0.18	0.009	0.06	8.78	0.60
200_1d	2.65	1.40	2.84	0.14	0.007	0.05	6.61	0.59
200_1w	49.42	1.40	28.77	2.15	0.107	0.07	32.60	0.19
200_2b	5.97	1.21	3.00	0.14	0.007	0.05	6.55	0.58
200_2d	2.52	1.21	2.46	0.11	0.006	0.05	5.76	0.64
200_2w	51.44	1.21	31.89	2.29	0.114	0.07	32.95	0.18
200_sb	9.01	1.39	4.12	0.17	0.008	0.04	6.71	0.49
200_sd	2.27	1.39	2.72	0.07	0.003	0.02	3.32	0.61
200_sw	47.36	1.39	28.36	1.96	0.098	0.07	29.98	0.19
20122_1b	30.94	1.53	11.76	1.97	0.098	0.17	46.58	0.29
20122_1d	6.41	1.53	3.39	0.39	0.020	0.12	17.30	0.54
20122_1w	41.25	1.53	20.25	2.85	0.142	0.14	51.52	0.22
20122_2b	16.89	1.37	6.14	0.60	0.030	0.10	19.69	0.40
20122_2d	2.98	1.37	2.93	0.20	0.010	0.07	9.48	0.58
20122_2w	48.22	1.37	27.06	2.83	0.141	0.10	44.21	0.19
20122_sb	17.37	1.47	6.43	0.49	0.025	0.08	15.85	0.39
20122_sd	3.19	1.47	2.72	0.08	0.004	0.03	3.88	0.61
20122_sw	40.39	1.47	21.43	1.71	0.085	0.08	30.10	0.22
20123_1b	8.11	1.33	3.67	0.19	0.009	0.05	7.91	0.52
20123_1d	1.61	1.33	2.59	0.14	0.007	0.05	6.88	0.62
20123_1w	52.69	1.33	31.07	2.41	0.120	0.08	35.11	0.18
20123_2b	21.49	1.66	7.82	0.80	0.040	0.10	23.20	0.36
20123_2d	4.55	1.66	3.12	0.21	0.010	0.07	9.52	0.57
20123_2w	32.55	1.66	15.84	1.61	0.080	0.10	32.87	0.25
20123_sb	19.71	1.54	8.24	0.70	0.035	0.08	19.75	0.35
20123_sd	1.95	1.54	2.81	0.06	0.003	0.02	2.99	0.60
20123_sw	36.96	1.54	20.71	1.90	0.094	0.09	33.87	0.22
2027_1b	7.44	1.53	3.94	0.13	0.006	0.03	5.15	0.50
2027_1d	1.54	1.53	2.69	0.06	0.003	0.02	2.97	0.61
2027_1w	44.38	1.53	26.75	1.72	0.086	0.06	27.11	0.19
2027_2b	22.63	1.53	8.43	0.93	0.047	0.11	26.15	0.34
2027_2d	5.34	1.53	3.29	0.30	0.015	0.09	13.32	0.55
2027_2w	42.86	1.53	22.80	2.38	0.119	0.10	40.60	0.21
2027_sb	10.49	1.44	3.77	0.13	0.006	0.03	5.40	0.51
2027_sd	5.16	1.44	2.68	0.07	0.003	0.03	3.41	0.61
2027_sw	45.55	1.44	24.49	1.53	0.076	0.06	25.08	0.20
2065_1b	17.55	1.47	6.03	0.43	0.021	0.07	14.22	0.41
2065_1d	4.15	1.47	2.96	0.19	0.010	0.07	9.21	0.58
2065_1w	44.58	1.47	24.19	2.02	0.101	0.08	33.39	0.20
2065_2b	19.52	1.48	7.36	0.68	0.034	0.09	20.53	0.37
2065_2d	4.91	1.48	3.12	0.24	0.012	0.08	10.90	0.57
2065_2w	42.22	1.48	22.96	2.22	0.111	0.10	37.69	0.21
2065_sb	13.39	1.37	5.03	0.19	0.010	0.04	6.92	0.45
2065_sd	2.09	1.37	2.55	0.04	0.002	0.02	2.15	0.63
2065_sw	45.70	1.37	27.99	2.41	0.120	0.09	37.07	0.19

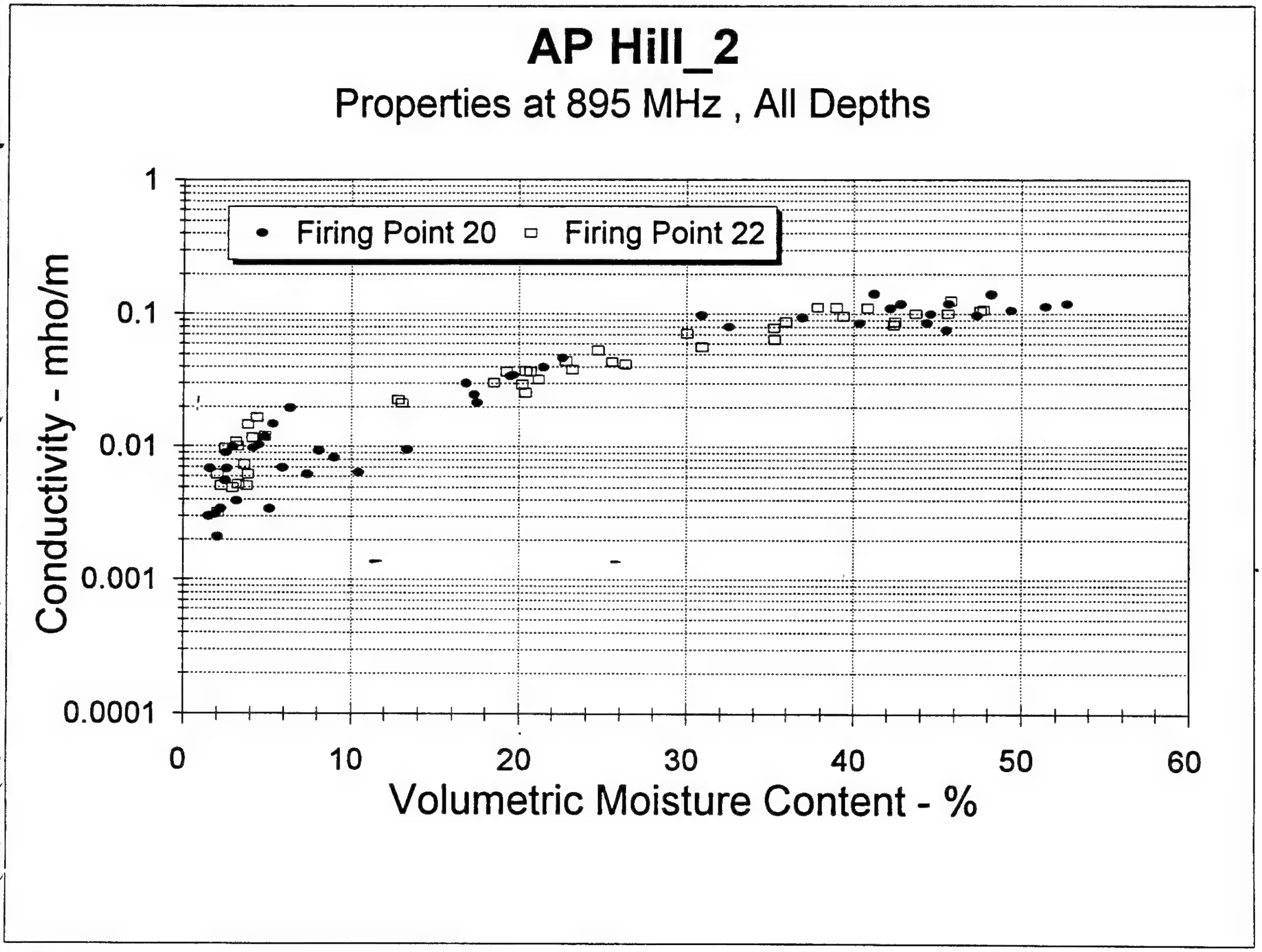
Fort AP Hill_2 Soil Properties at 895 MHz

Firing Point 22

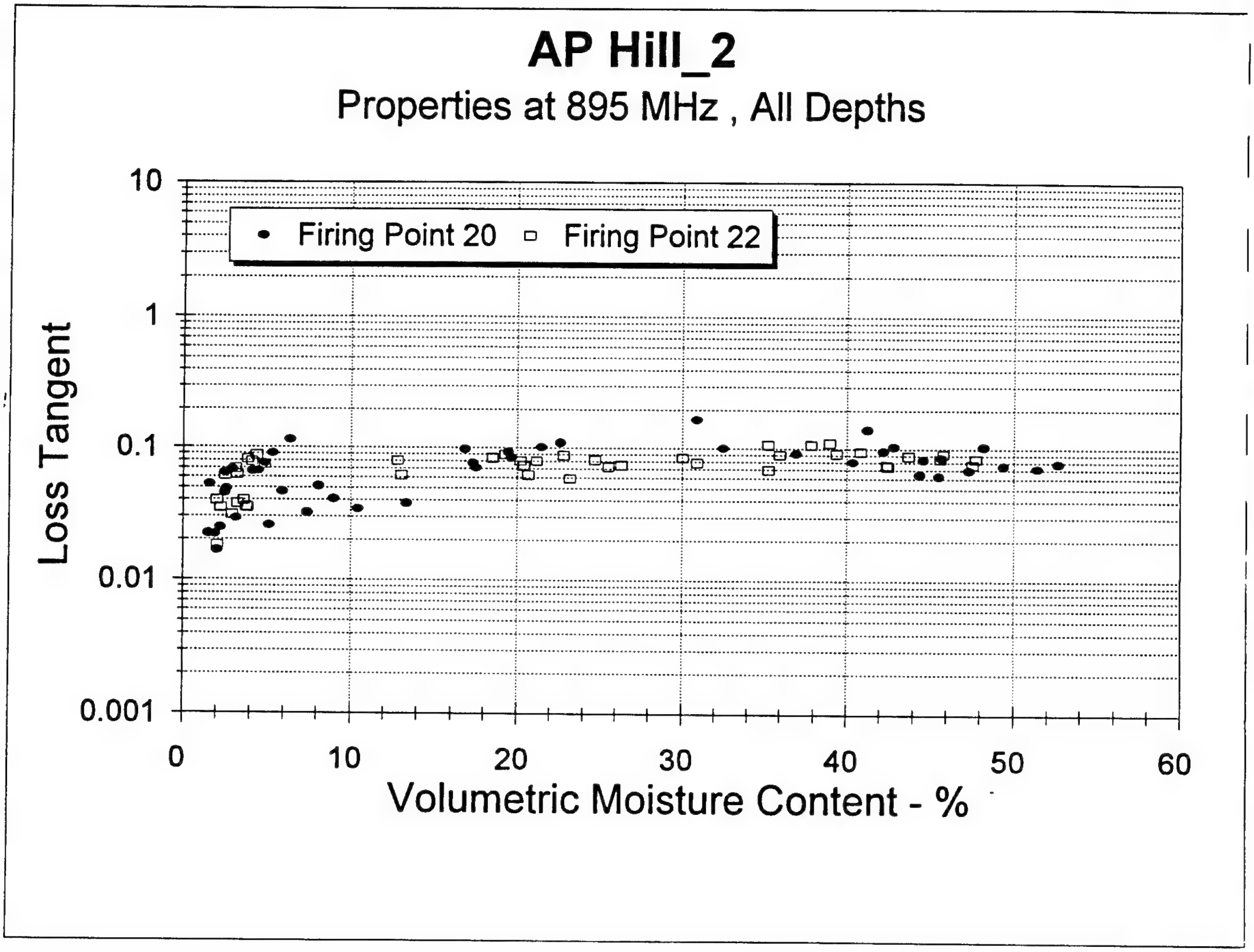
File Name	Vol Moist	Dry Dens g/cc	Re(eps)	Im(eps)	Cond mho/m	Loss Tan	Attn dB/m	Norm Vel
22122_1b	19.30	1.53	8.28	0.74	0.037	0.09	21.01	0.35
22122_1d	3.88	1.53	3.62	0.30	0.015	0.08	12.63	0.53
22122_1w	45.79	1.53	27.52	2.52	0.125	0.09	39.06	0.19
22122_2b	20.45	1.83	10.15	0.74	0.037	0.07	19.01	0.31
22122_2d	2.94	1.83	3.20	0.10	0.005	0.03	4.49	0.56
22122_2w	35.24	1.83	14.72	1.58	0.079	0.11	33.54	0.26
22122_sb	13.05	1.69	6.91	0.43	0.021	0.06	13.24	0.38
22122_sd	2.04	1.69	3.16	0.13	0.006	0.04	5.73	0.56
22122_sw	35.25	1.69	18.63	1.29	0.064	0.07	24.37	0.23
22123_1b	21.20	1.53	8.05	0.65	0.032	0.08	18.57	0.35
22123_1d	4.87	1.53	3.23	0.24	0.012	0.07	10.90	0.56
22123_1w	43.69	1.53	22.73	2.03	0.101	0.09	34.59	0.21
22123_2b	12.82	1.51	5.64	0.45	0.023	0.08	15.48	0.42
22123_2d	3.22	1.51	3.20	0.20	0.010	0.06	9.11	0.56
22123_2w	45.59	1.51	23.97	2.04	0.101	0.08	33.81	0.20
22123_sb	18.55	1.55	7.28	0.61	0.030	0.08	18.43	0.37
22123_sd	3.80	1.55	2.91	0.10	0.005	0.04	4.93	0.59
22123_sw	39.36	1.55	20.99	1.95	0.097	0.09	34.56	0.22
2227_1b	26.33	1.51	11.26	0.84	0.042	0.07	20.36	0.30
2227_1d	3.15	1.51	3.17	0.22	0.011	0.07	10.05	0.56
2227_1w	42.47	1.51	23.81	1.76	0.087	0.07	29.29	0.20
2227_2b	37.85	1.66	21.20	2.27	0.113	0.11	40.12	0.22
2227_2d	4.37	1.66	3.81	0.33	0.017	0.09	13.91	0.51
2227_2w	38.96	1.66	20.33	2.26	0.113	0.11	40.76	0.22
2227_sb	47.54	1.31	28.01	2.13	0.106	0.08	32.72	0.19
2227_sd	2.27	1.31	2.92	0.10	0.005	0.03	4.85	0.59
2227_sw	42.39	1.31	21.97	1.67	0.083	0.08	28.91	0.21
222_1b	20.41	1.40	7.01	0.52	0.026	0.07	15.88	0.38
222_1d	4.12	1.40	2.99	0.23	0.012	0.08	11.02	0.58
222_1w	47.74	1.40	25.74	2.18	0.108	0.08	34.88	0.20
222_2b	22.82	1.57	10.11	0.89	0.044	0.09	22.77	0.31
222_2d	2.51	1.57	3.18	0.20	0.010	0.06	8.92	0.56
222_2w	40.82	1.57	23.32	2.24	0.111	0.10	37.71	0.21
222_sb	20.23	1.55	7.38	0.59	0.029	0.08	17.65	0.37
222_sd	3.26	1.55	2.82	0.11	0.005	0.04	5.12	0.60
222_sw	35.92	1.55	19.37	1.76	0.088	0.09	32.47	0.23
2265_1b	23.21	1.99	13.00	0.77	0.038	0.06	17.27	0.28
2265_1d	3.65	1.99	3.72	0.15	0.007	0.04	6.22	0.52
2265_1w	25.57	1.99	12.08	0.88	0.044	0.07	20.61	0.29
2265_2b	20.71	1.94	11.93	0.74	0.037	0.06	17.47	0.29
2265_2d	2.09	1.94	3.56	0.06	0.003	0.02	2.78	0.53
2265_2w	24.72	1.94	13.13	1.08	0.054	0.08	24.14	0.28
2265_sb	30.08	1.82	16.85	1.44	0.072	0.09	28.56	0.24
2265_sd	3.87	1.82	3.54	0.12	0.006	0.04	5.38	0.53
2265_sw	30.94	1.82	14.56	1.14	0.057	0.08	24.35	0.26


AP Hill_2
Properties at 895 MHz , All Depths
Firing Point 20
Firing Point 22
Re(Dielectric Constant)
Volumetric Moisture Content - %
0
10
20
30
40
50
60

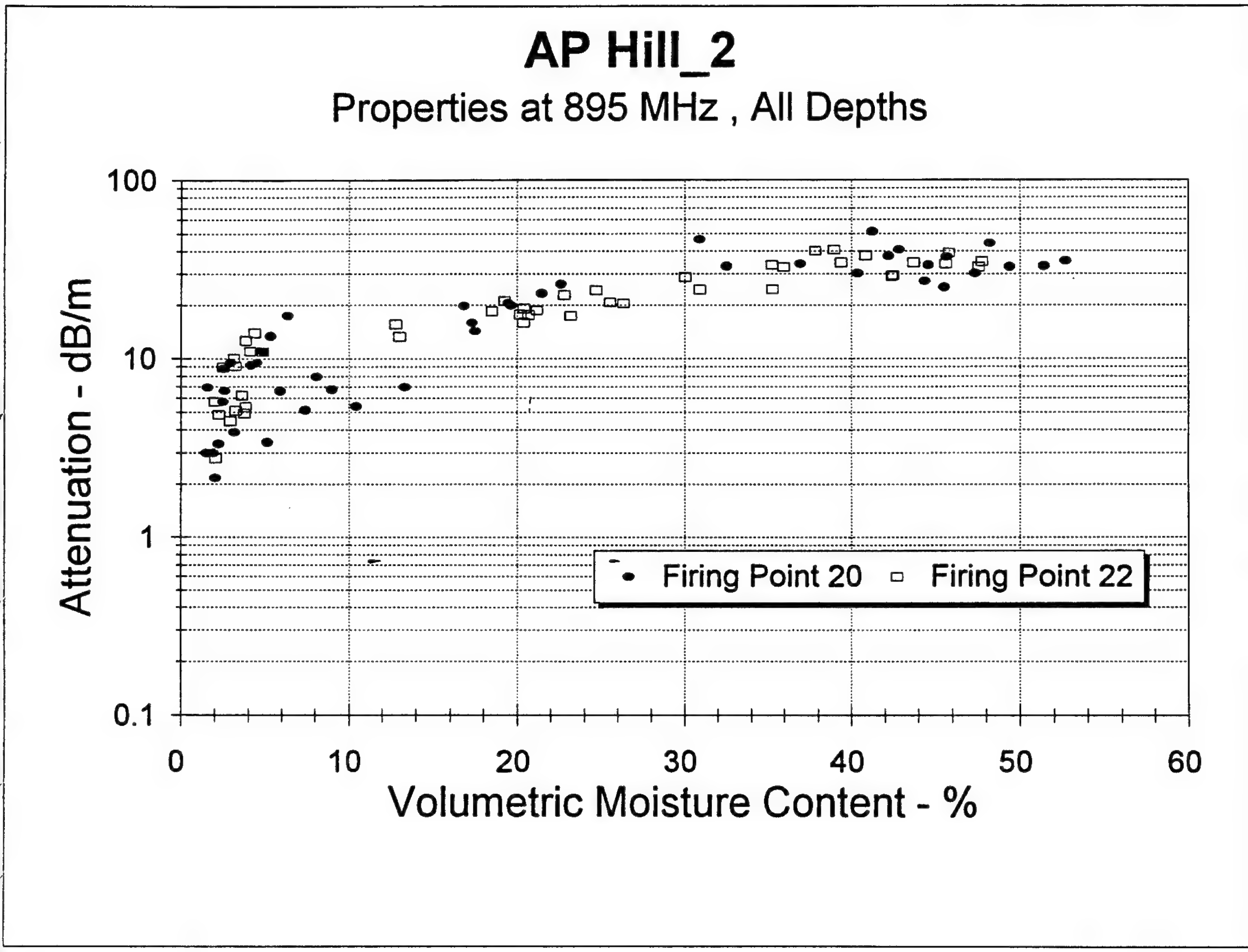

AP Hill_2
Properties at 895 MHz , All Depths
Firing Point 20
Firing Point 22
Im(Dielectric Constant)
50
40
30
20
10
0
0
10
20
30
40
50
60
Volumetric Moisture Content - %

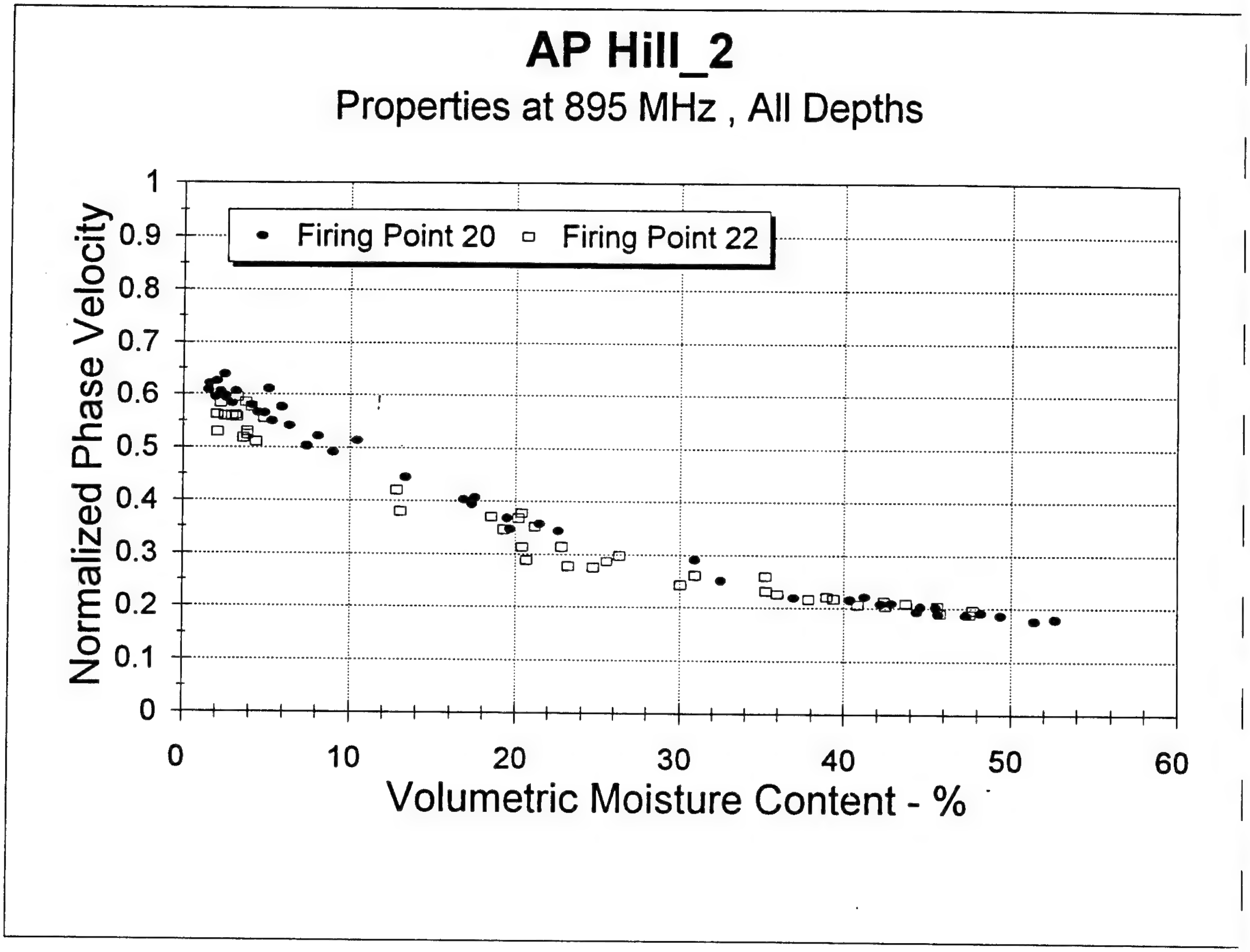


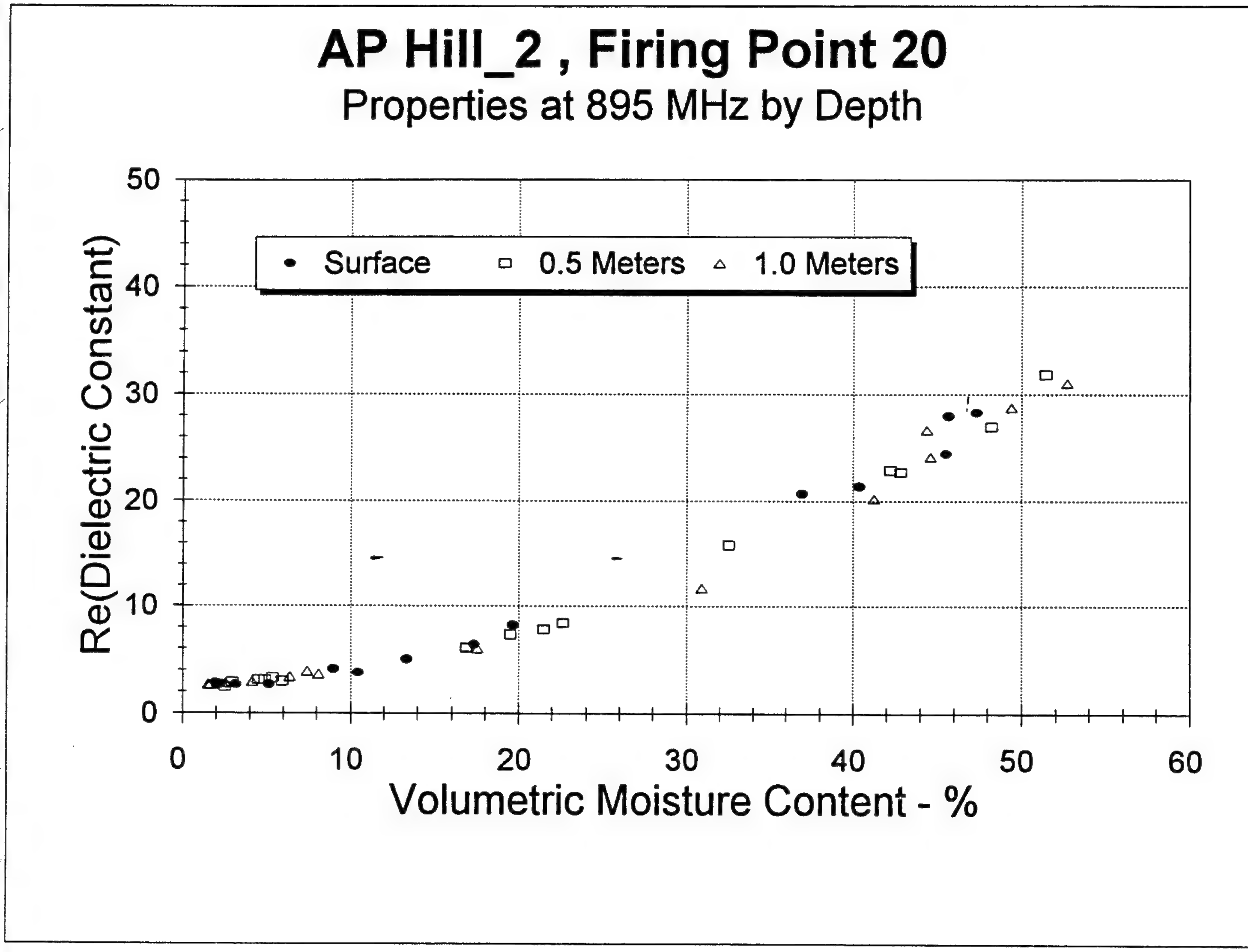
AP Hill_2
Properties at 895 MHz , All Depths
Firing Point 20
Firing Point 22
Conductivity - mho/m
1
0.1
0.01
0.001
0.0001
0
10
20
30
40
50
60
Volumetric Moisture Content - %

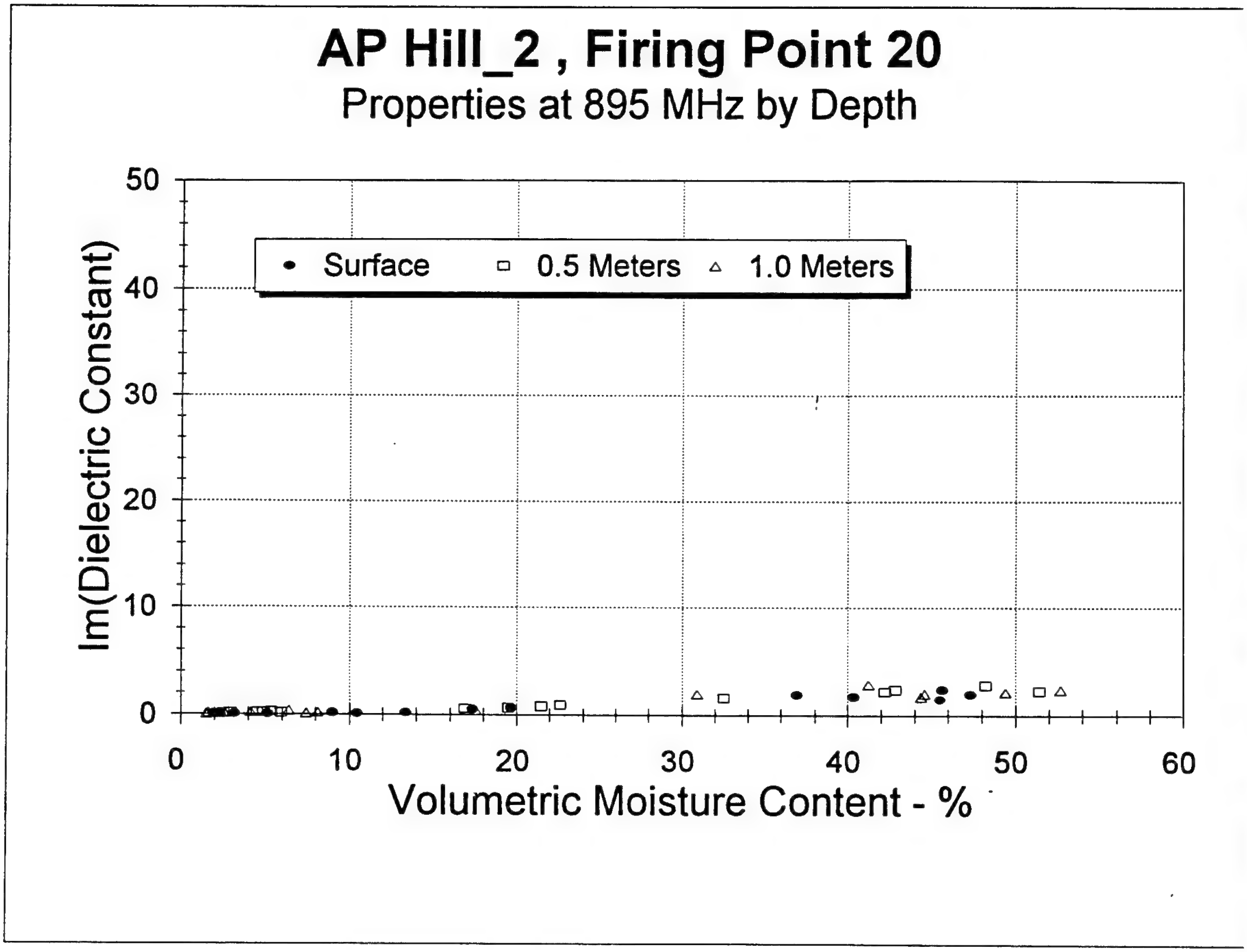


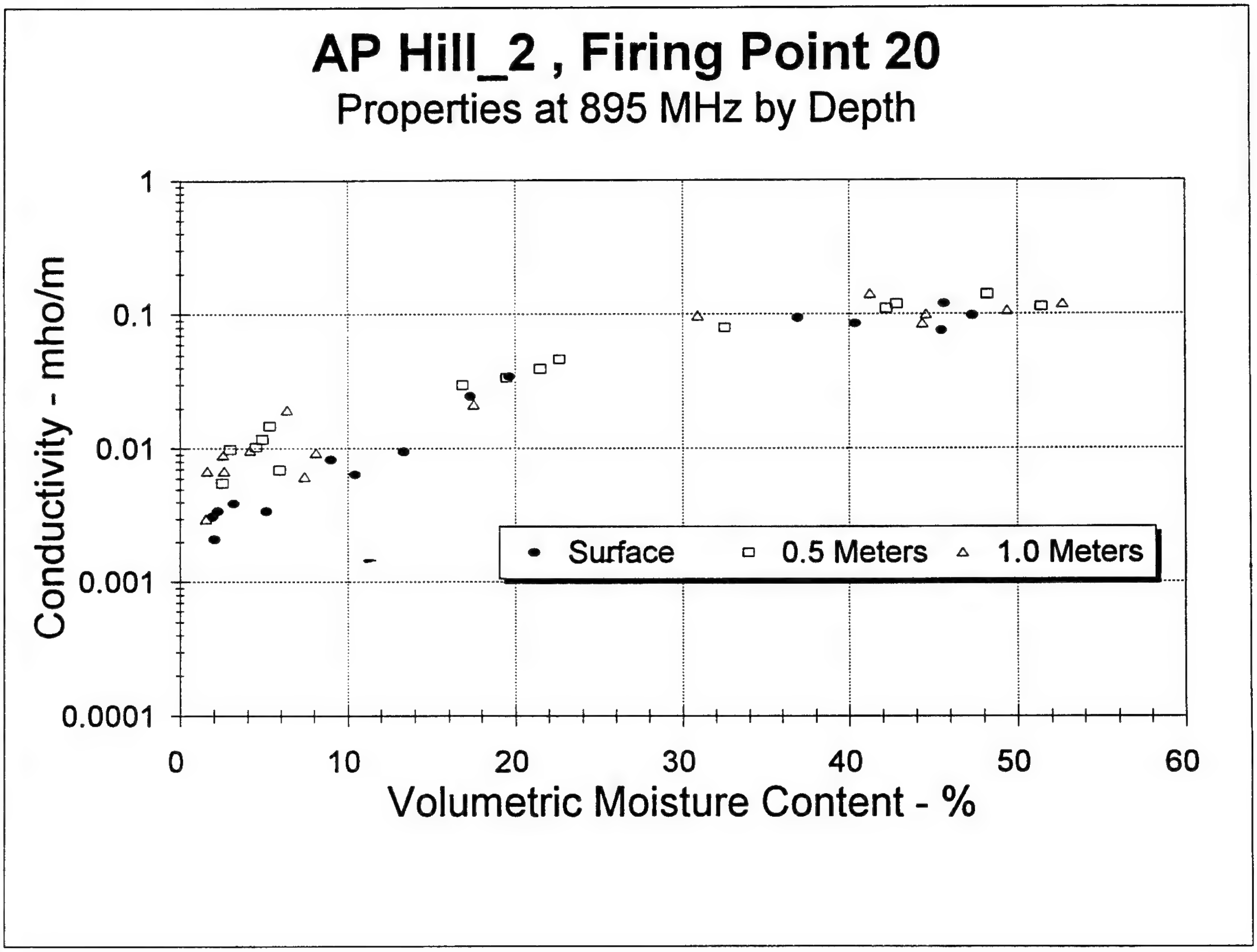
AP Hill_2
Properties at 895 MHz , All Depths
Firing Point 20
Firing Point 22
Loss Tangent
10
1
0.1
0.01
0.001
0
10
20
30
40
50
60
Volumetric Moisture Content - %

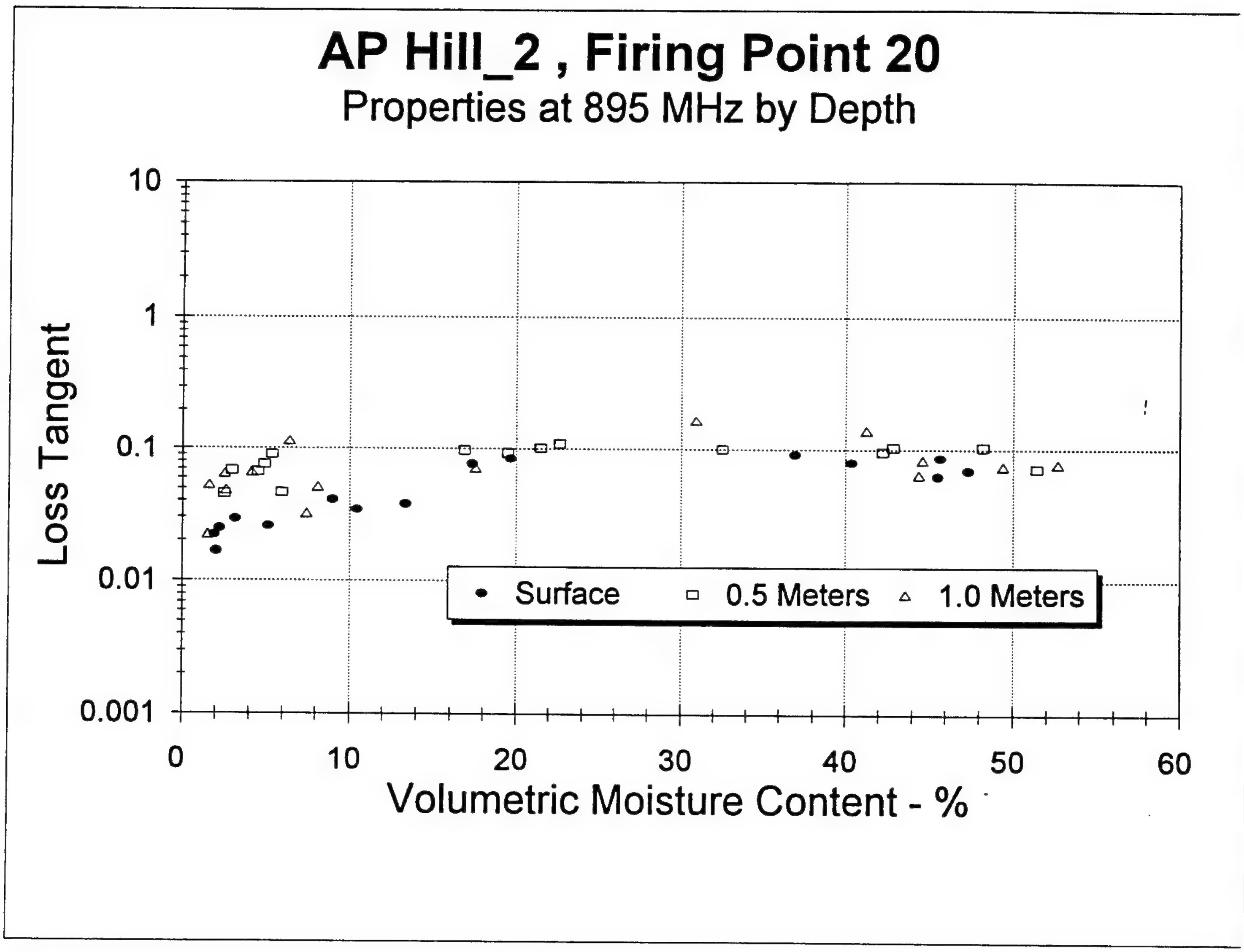

AP Hill_2
Properties at 895 MHz , All Depths
100
10
1
0.1
Attenuation - dB/m
0
10
20
30
40
50
60
Volumetric Moisture Content - %
Firing Point 20
Firing Point 22


AP Hill_2
Properties at 895 MHz , All Depths
Firing Point 20
Firing Point 22
Normalized Phase Velocity
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
10
20
30
40
50
60
Volumetric Moisture Content - %

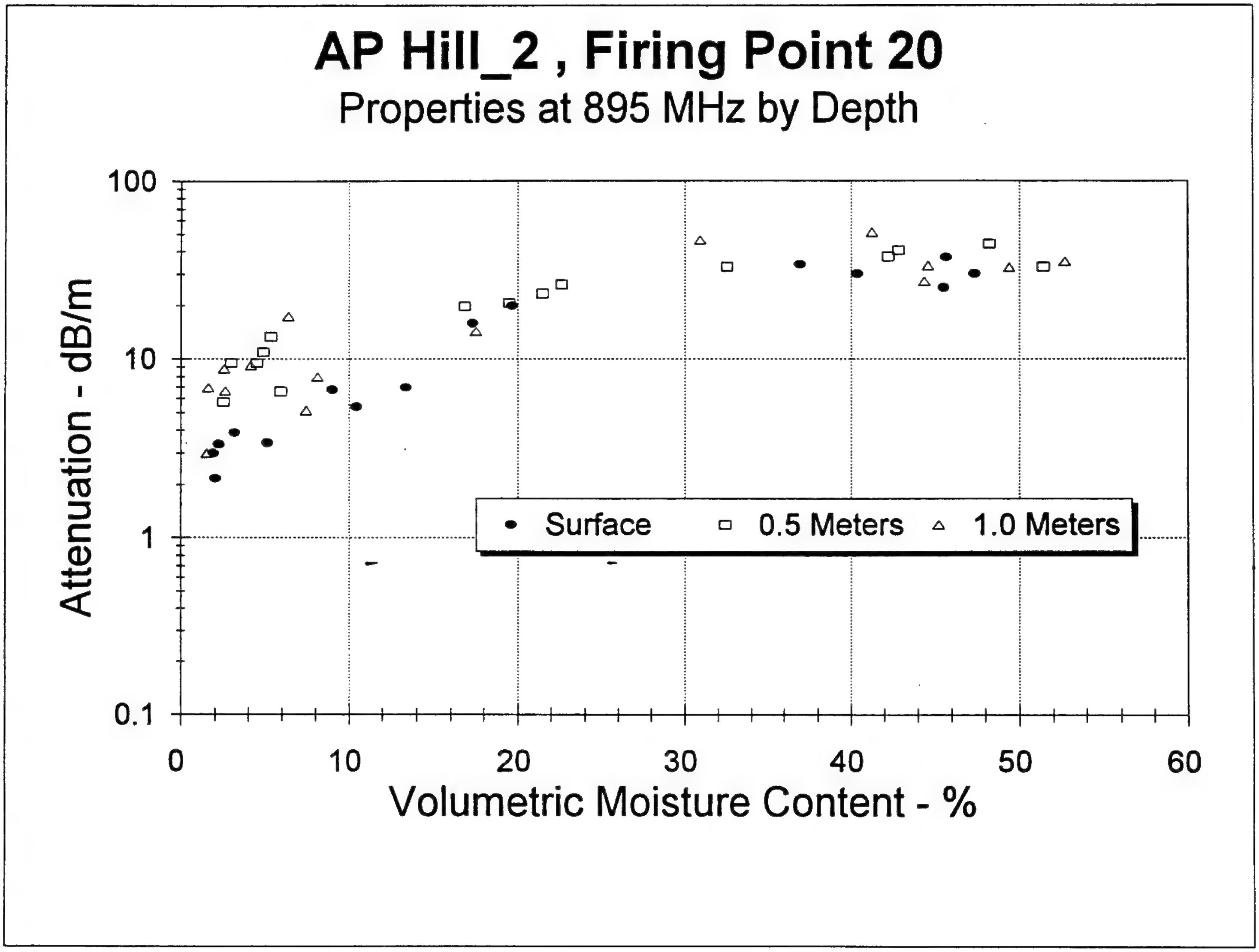

AP Hill_2 , Firing Point 20
Properties at 895 MHz by Depth
Surface
0.5 Meters
1.0 Meters
Re(Dielectric Constant)
Volumetric Moisture Content - %
0
10
20
30
40
50
60


AP Hill_2 , Firing Point 20
Properties at 895 MHz by Depth
Im(Dielectric Constant)
50
40
30
20
10
0
Surface
0.5 Meters
1.0 Meters
0
10
20
30
40
50
60
Volumetric Moisture Content - %

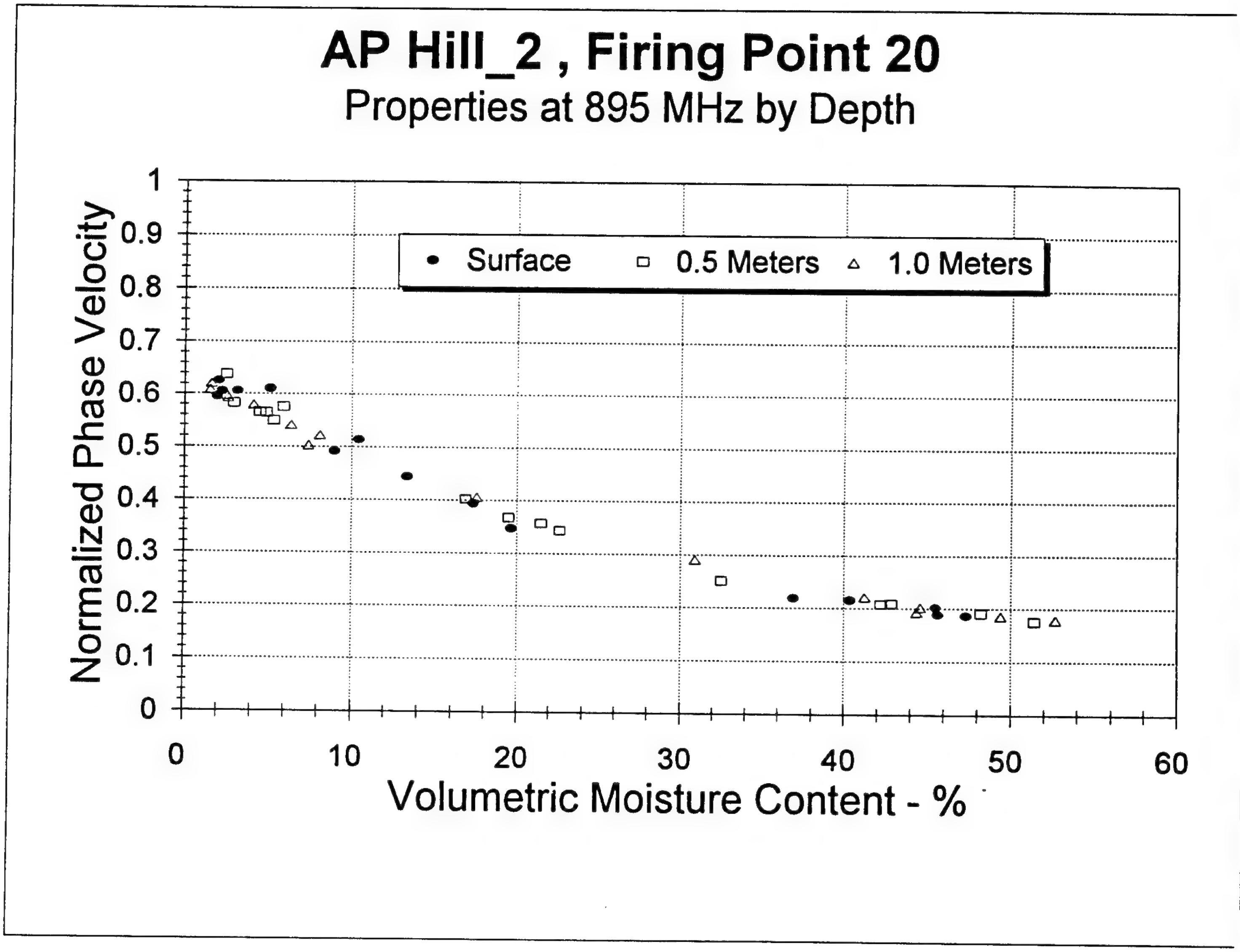

AP Hill_2 , Firing Point 20
Properties at 895 MHz by Depth
Conductivity - mhho/m
1
0.1
0.01
0.001
0.0001
0
10
20
30
40
50
60
Volumetric Moisture Content - %
Surface
0.5 Meters
1.0 Meters



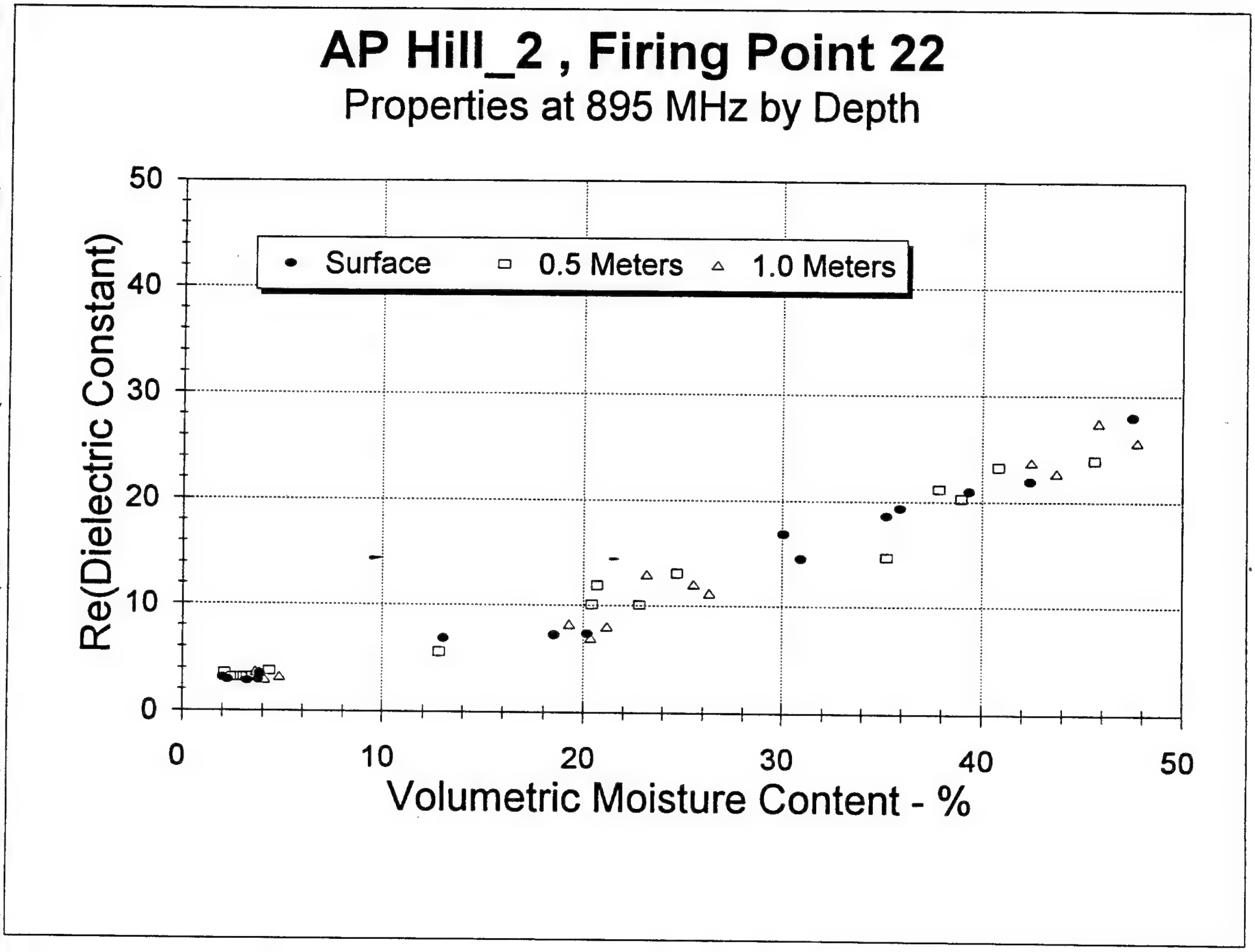
AP Hill_2 , Firing Point 20
Properties at 895 MHz by Depth
10
1
0.1
0.01
0.001
Loss Tangent
0
10
20
30
40
50
60
Volumetric Moisture Content - %
Surface
0.5 Meters
1.0 Meters



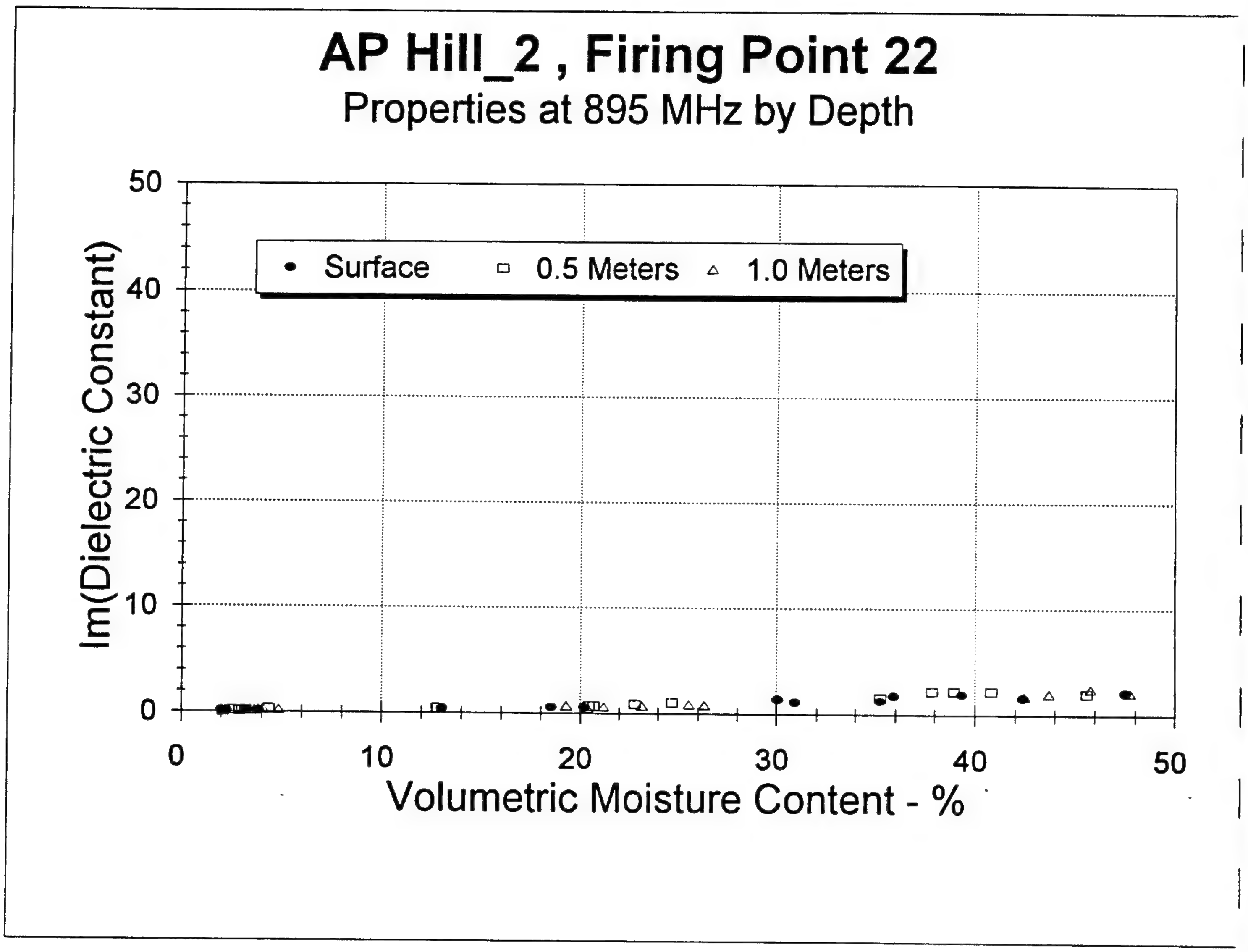
AP Hill_2 , Firing Point 20
Properties at 895 MHz by Depth
Attenuation - dB/m
100
10
1
0.1
0
10
20
30
40
50
60
Volumetric Moisture Content - %
Surface
0.5 Meters
1.0 Meters



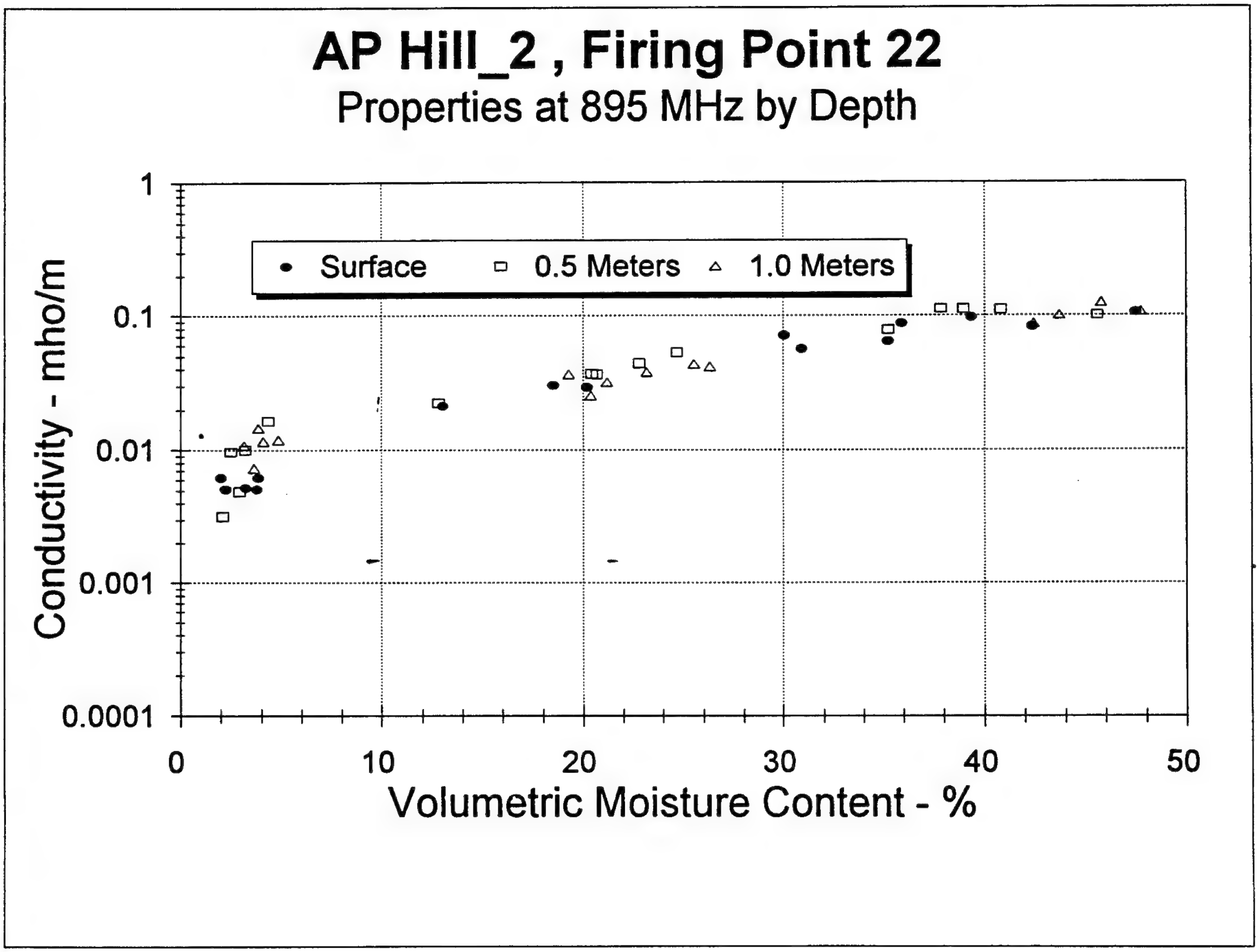
AP Hill_2 , Firing Point 20
Properties at 895 MHz by Depth
Surface
0.5 Meters
1.0 Meters
Normalized Phase Velocity
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
10
20
30
40
50
60
Volumetric Moisture Content - %



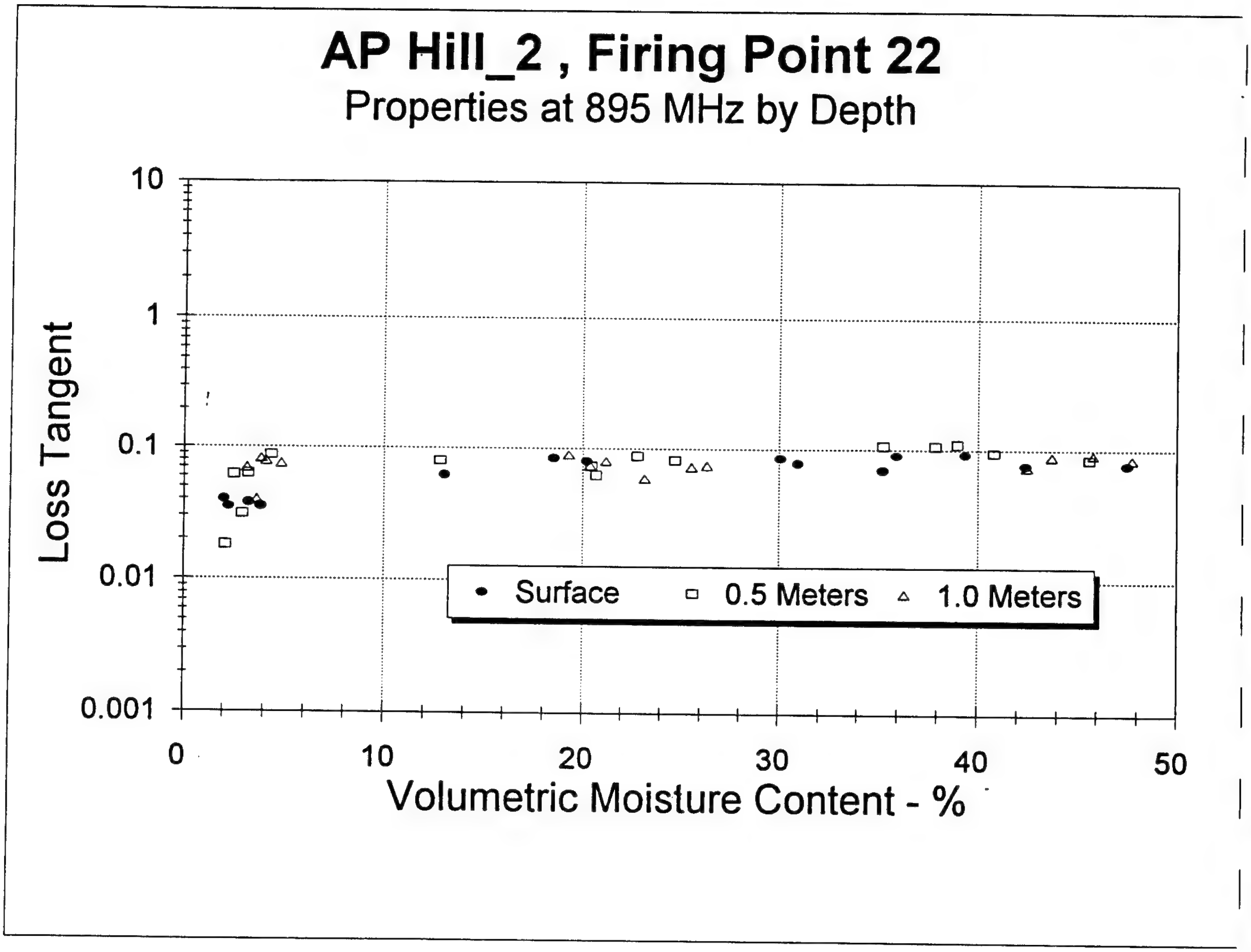
AP Hill_2 , Firing Point 22
Properties at 895 MHz by Depth
Surface
0.5 Meters
1.0 Meters
Re(Dielectric Constant)
0
10
20
30
40
50
Volumetric Moisture Content - %



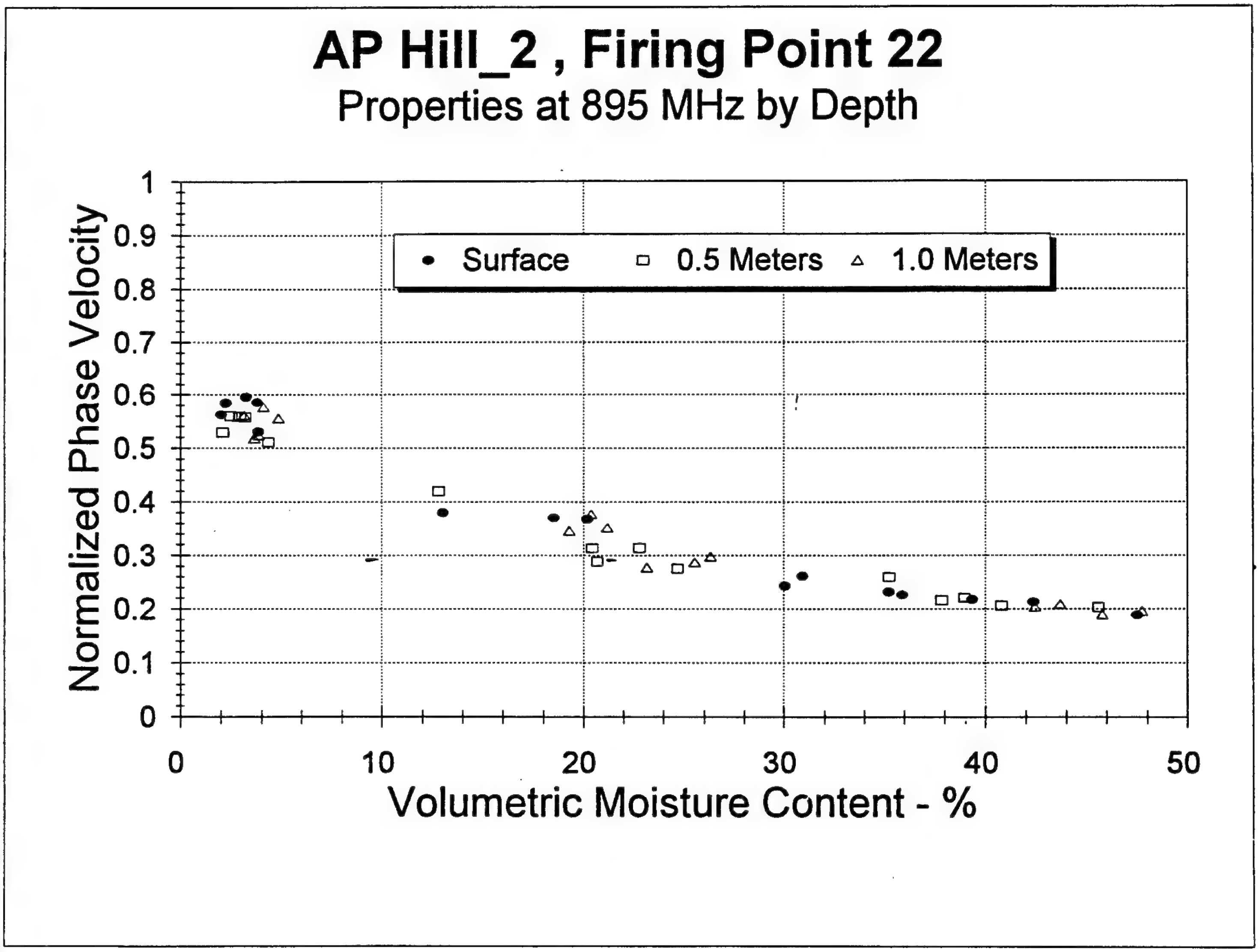
AP Hill_2 , Firing Point 22
Properties at 895 MHz by Depth
Surface
0.5 Meters
1.0 Meters
Im(Dielectric Constant)
0
10
20
30
40
50
Volumetric Moisture Content - %



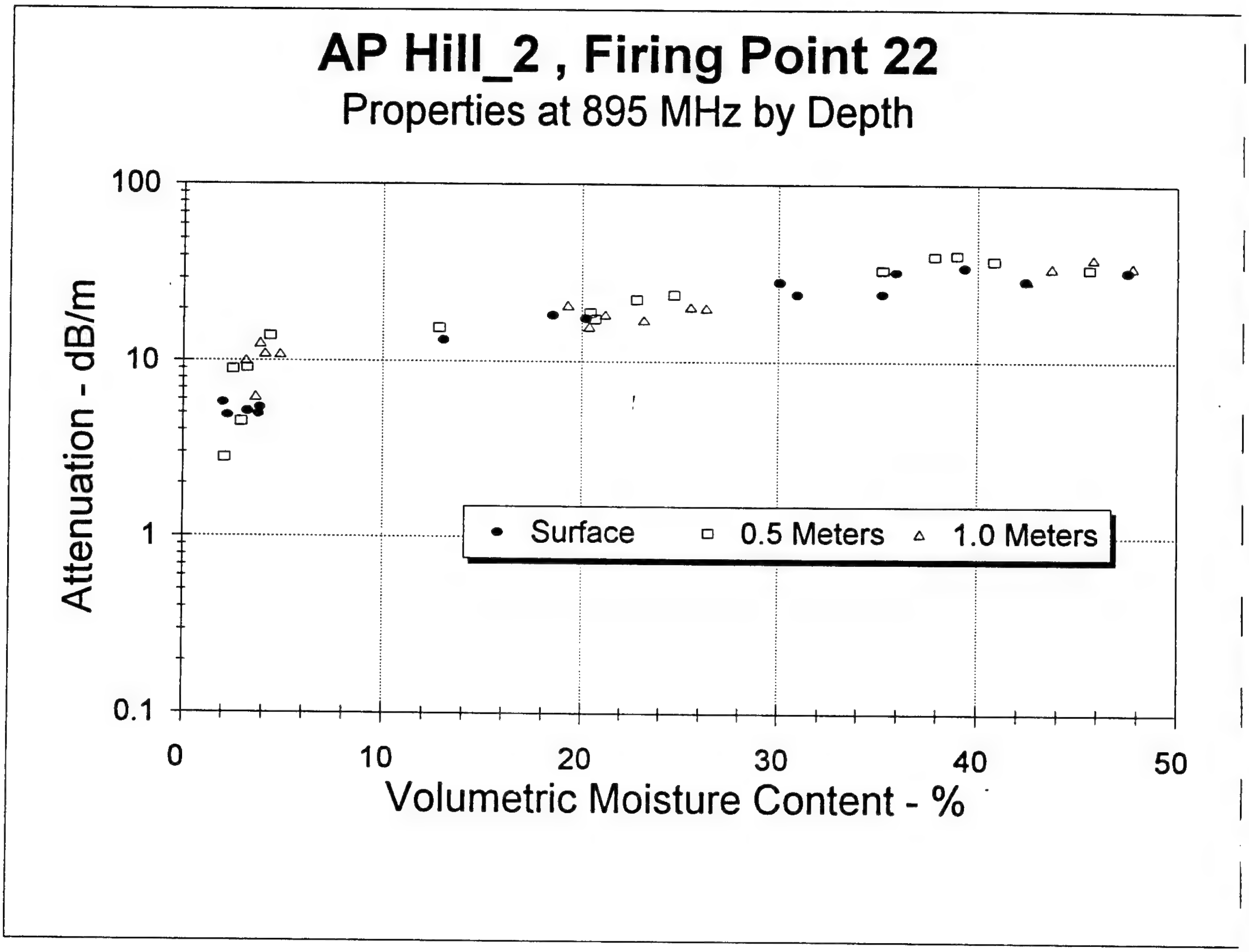
AP Hill_2 , Firing Point 22
Properties at 895 MHz by Depth
Surface
0.5 Meters
1.0 Meters
Conductivity - mho/m
1
0.1
0.01
0.001
0.0001
0
10
20
30
40
50
Volumetric Moisture Content - %



AP Hill_2 , Firing Point 22
Properties at 895 MHz by Depth
Loss Tangent
10
1
0.1
0.01
0.001
0
10
20
30
40
50
Volumetric Moisture Content - %
Surface
0.5 Meters
1.0 Meters



AP Hill_2 , Firing Point 22
Properties at 895 MHz by Depth
Normalized Phase Velocity
Volumetric Moisture Content - %
Surface
0.5 Meters
1.0 Meters
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
10
20
30
40
50



AP Hill_2 , Firing Point 22
Properties at 895 MHz by Depth
Attenuation - dB/m
100
10
1
0.1
0
10
20
30
40
50
Volumetric Moisture Content - %
Surface
0.5 Meters
1.0 Meters

20 August 1996

Data Report

Dielectric Properties of Soils

Fort A.P. Hill, VA

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Introduction

This report contains dielectric property measurement results for soils. The original data were collected in the form of the real and imaginary parts of the complex dielectric constant versus frequency. The data collection apparatus was a Hewlet-Packard 8510C Vector Network Analyzer System with an S-Parameter Test Set. Software developed at the U.S. Army Engineer Waterways Experiment Station was used to convert S-parameter measurements at selected frequencies into a complex dielectric constant. The soils were assumed to be nonmagnetic. Other useful electromagnetic properties were calculated from the dielectric constant and frequency, including an equivalent electrical conductivity, the loss tangent, power attenuation, and a normalized phase velocity. The section entitled, "Fundamental Relationships," contains the formulae used to calculate these properties. Additional physical parameters of the soil samples that are included in the report include their dry density, volumetric moisture content, and temperature.

Measurement results and calculated parameters are displayed in three sections. The first includes properties at a selected frequency(ies) and displayed as a function of volumetric moisture content. The intent of presenting data in this way is to demonstrate the experimental observation that the real part of the dielectric constant, as well as the normalized phase velocity are strong functions of volumetric moisture and reasonably independent of soil texture. Other parameters are clearly dependent on soil texture, and, given enough data from several different types of soils, their graphs versus moisture content would show a great deal of scatter. A second set of graphs and tables contain parameters plotted versus frequency for each individual sample tested with the laboratory apparatus. Finally, a third set of graphs contain parameters plotted against frequency for all of the samples. This was done to simply demonstrate that, when viewed as a function of frequency, soil electromagnetic properties are strong functions of moisture and texture.

For additional details on how the data were collected, please contact me at the U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, (voice: 601-634-2855, FAX: 601-634-2732, e-mail: curtisj@ex1.wes.army.mil).

Source of Soil Samples

The laboratory measurements reported, herein, were performed on soils from Fort A.P. Hill, ~~NJ.~~ VA Near-surface bag samples were collected on 21 March, 1996, by Mr. Jose Llopis, from the Goetechnical Laboratory at the U.S. Army Engineer Waterways Experiment Station. Mr. Llopis' sketches of sample locations are included as the last item in this data report.

Gradation curves of the three soils measured in this study were provided to the Fort Belvoir, Countermine Directorate, Mine Detection Office in May of 1996. These curves and supporting Atterberg limits data indicated little, if any, clay content in the Fort A.P. Hill soils. The absence of swelling clay minerals was confirmed during the collection of electromagnetic property data, as no change in sample volume was observed following the addition of water to the samples.

Fundamental Relationships

Assuming plane harmonic wave propagation in a lossy, non-magnetic, unbounded medium, the wave amplitude function may be written:

$$e^{i(kx - \omega t)}$$

where

$k \quad = \beta + i\alpha \quad = \omega N/c$

is the complex propagation constant,

β is the phase constant,

α is the amplitude attenuation factor,

ω is the radial frequency,

N is the complex index of refraction,

c is the velocity of light in a vacuum,

i is the symbol designating an imaginary quantity = $\sqrt{-1}$,

x is a space coordinate, and

t is time.

Furthermore,

$$N^2 = \epsilon = \epsilon' + \epsilon''$$

where ϵ is the relative complex dielectric constant, which, along with the electrical conductivity from Ohm's Law, represents the electrical properties of the medium. The interpretation of these properties as used in this study is that the conductivity, σ , accounts for current due to free charged particle motion, while the imaginary part of the complex dielectric constant, ϵ'' , accounts for displacement current losses (those due to the electric polarization of the medium). When both conduction and displacement currents are considered, one finds two terms in Ampere's law for current flow that represent losses (or a shift in phase), one containing the electrical conductivity and one containing the imaginary part of the dielectric constant. While these two terms account

for different loss mechanisms, most researchers use only one term or the other to identify losses, with many users preferring to deal with the concept of electrical conductivity. In MKS units, the relationship between the two quantities is taken to be

$$\sigma = \epsilon'' \epsilon_0 \omega$$

where the units of conductivity are mhos/meter (or siemens/meter) and ϵ_0 is the permittivity of free space (8.85×10^{-12} farads/meter).

Squaring the expression for the complex propagation constant, substituting the expression for the square of the complex index of refraction, and equating real and imaginary components, one obtains two algebraic equations that relate the amplitude attenuation factor and phase constant to the complex dielectric constant:

$$\beta^2 - \alpha^2 = \frac{\omega^2}{c^2}\epsilon'$$

and

$$\alpha\beta = \frac{\omega^2 \epsilon''}{2c^2}$$

Solving these equations for the amplitude attenuation factor and for the phase constant results in the following expressions:

$$\alpha = \frac{\omega}{c}\left(\frac{\epsilon'}{2}\left(\sqrt{1 + \left(\frac{\epsilon''}{\epsilon'}\right)^2} - 1\right)\right)^{1/2}$$

and

$$\beta = \frac{\omega}{c}\left(\frac{\epsilon'}{2}\left(\sqrt{1 + \left(\frac{\epsilon''}{\epsilon'}\right)^2} + 1\right)\right)^{1/2}$$

The ϵ''/ϵ' ratio is also referred to as the loss tangent. Some researchers prefer to work with the electrical conductivity in place of the dielectric loss term.

Plane waves of constant phase will propagate with a velocity

$$v = \frac{\omega}{\beta} = c\left(\frac{\epsilon'}{2}\left(\sqrt{1 + \left(\frac{\epsilon''}{\epsilon'}\right)^2} + 1\right)\right)^{-1/2}$$

This phase velocity is not necessarily the speed with which the energy of the wave propagates through the

medium. The latter is refered to as the group velocity and can be calculated as the rate of change of radial frequency with respect to the phase constant. However, as long as the phase velocity is relatively constant over the range of frequencies of interest, then there is little difference between phase velocity and group velocity.

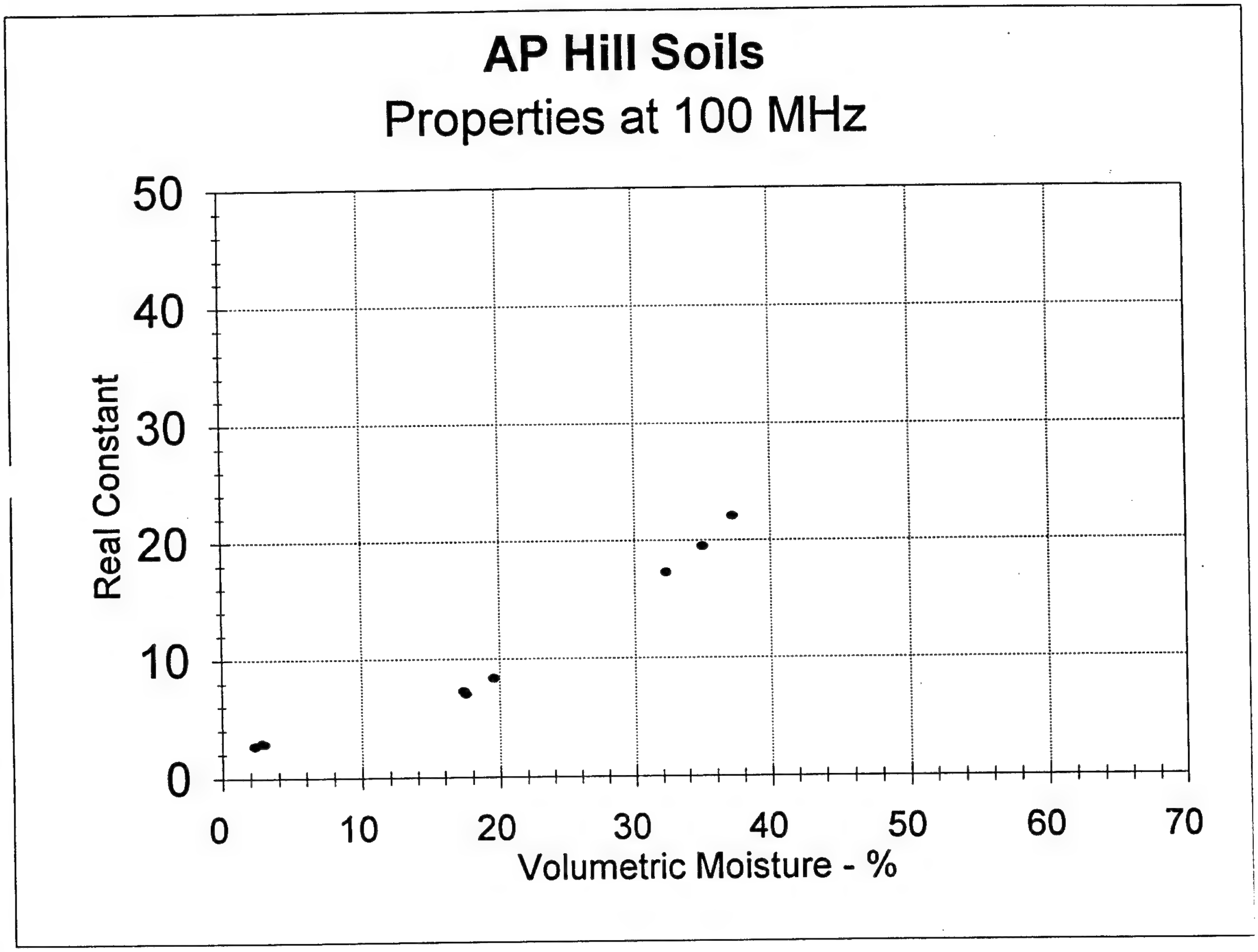
The power intensity of the plane electromagnetic wave decreases exponentially with depth of penetration by the factor, $e^{-2\alpha x}$, or, in one unit of distance traveled, a decrease of $e^{-2\alpha}$. Power attenuation expressed in decibels per meter can then be written as:

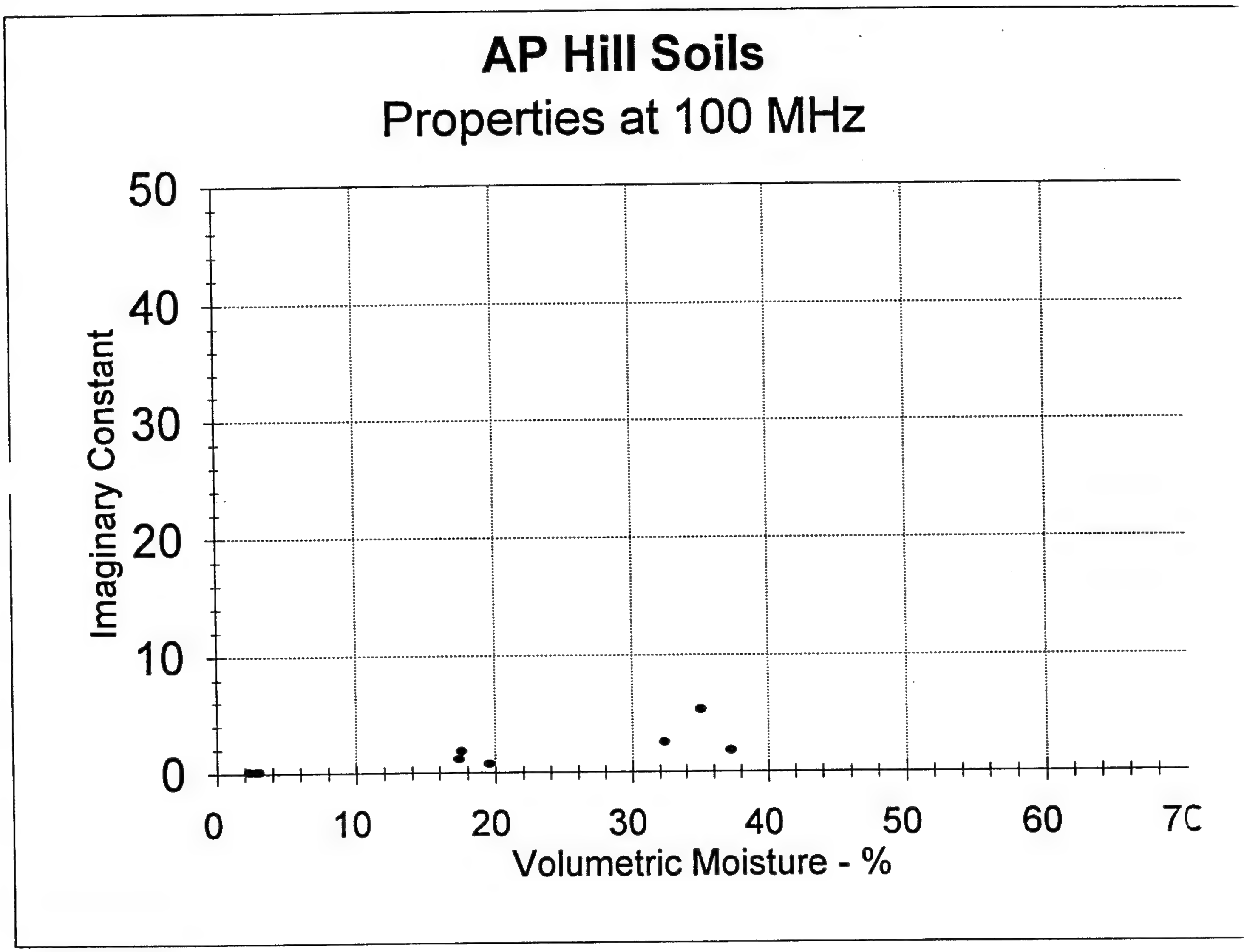
$$PL = -8.6859 \frac{\omega}{c} \left(\frac{\epsilon'}{2} \left(\sqrt{1 + \left(\frac{\epsilon''}{\epsilon'} \right)^2} - 1 \right) \right)^{1/2}$$

Fort A.P. Hill
Properties at 100 Mhz

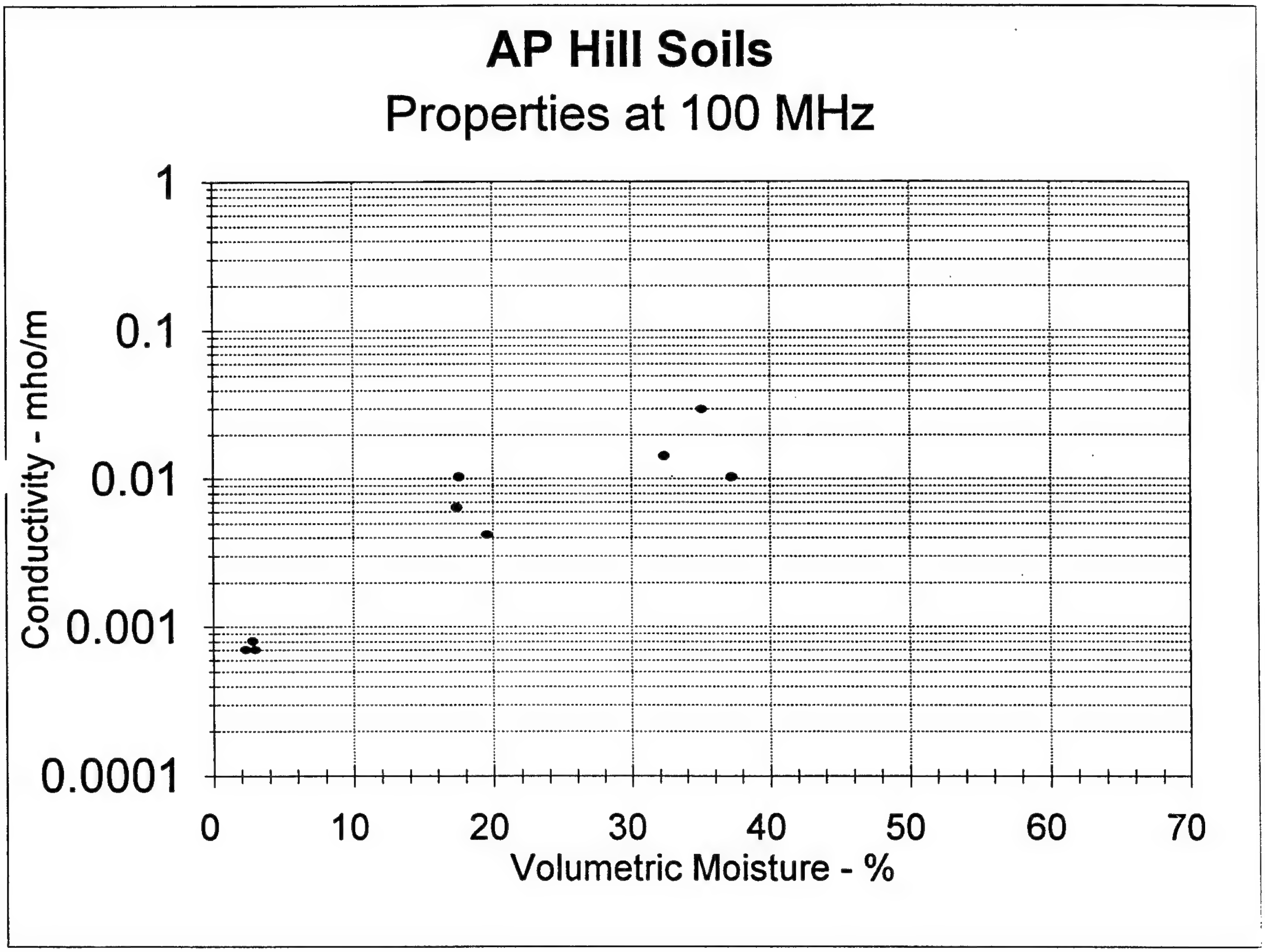
Fort A.P. Hill Soil Properties at 100 MHz

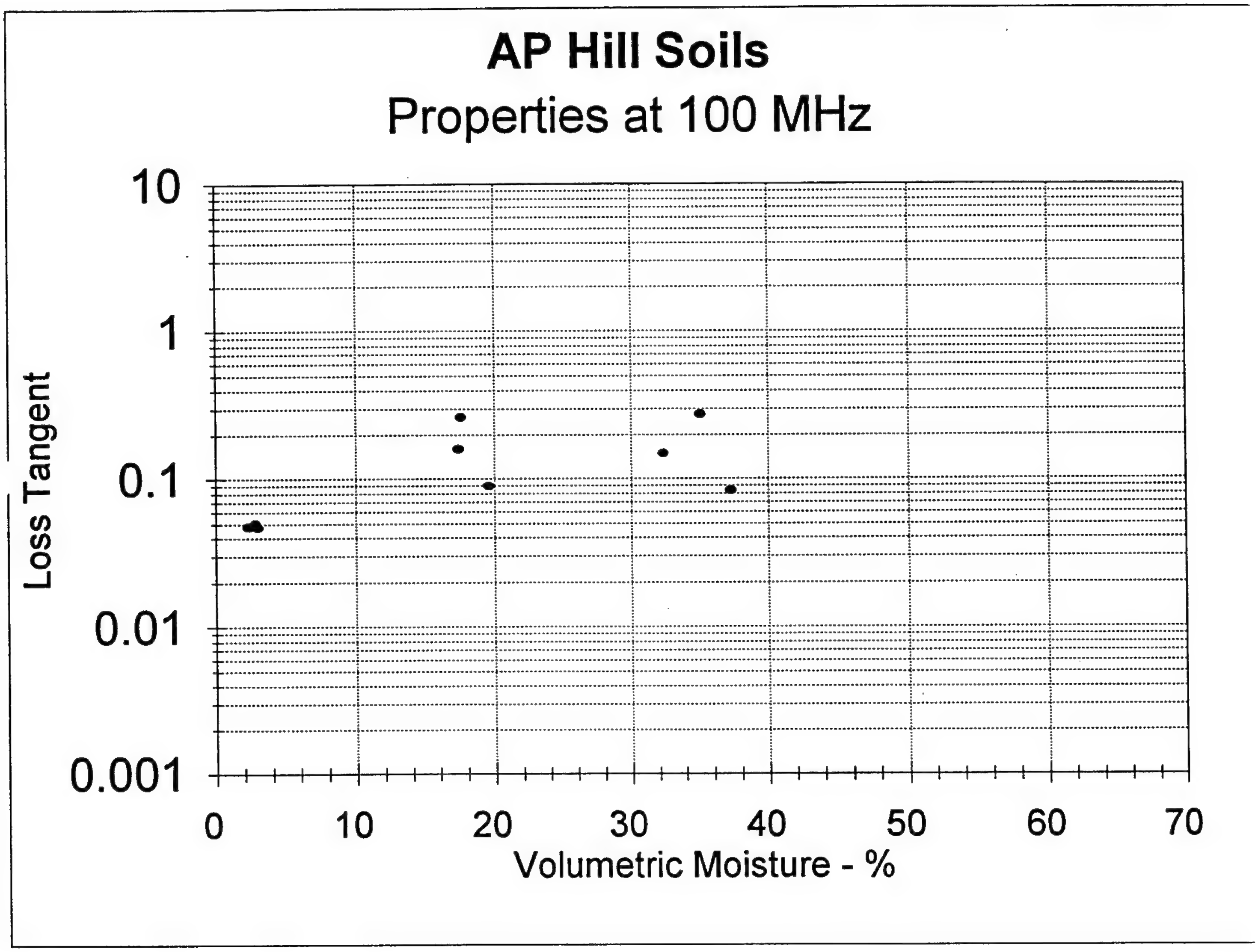
Vol. Moisture - %	Re(Dielectric)	Im(Dielectric)	Cond. - mho/m	Loss Tangent	Attn. - dB/m	Norm. Velocity	
2.3	2.7067	0.1293	0.0007	0.0478	0.7144	0.6077	
17.6	7.0409	1.8532	0.0103	0.2632	6.2993	0.3737	Off Road, dry density = 1.51 g/cc
35.1	19.5089	5.3602	0.0298	0.2748	10.9376	0.2243	
2.8	2.9602	0.1488	0.0008	0.0503	0.7866	0.581	
19.6	8.347	0.7527	0.0042	0.0902	2.3673	0.3458	Dart Road, dry density = 1.47 g/cc
37.3	22.0987	1.8511	0.0103	0.0838	3.5785	0.2125	
3	2.856	0.1338	0.0007	0.0469	0.7202	0.5916	
17.4	7.2575	1.1596	0.0064	0.1598	3.9028	0.37	Top 3", dry density = 1.48 g/cc
32.4	17.2805	2.5664	0.0143	0.1485	5.6003	0.2399	


AP Hill Soils
Properties at 100 MHz
Real Constant
Volumetric Moisture - %
0
10
20
30
40
50
60
70

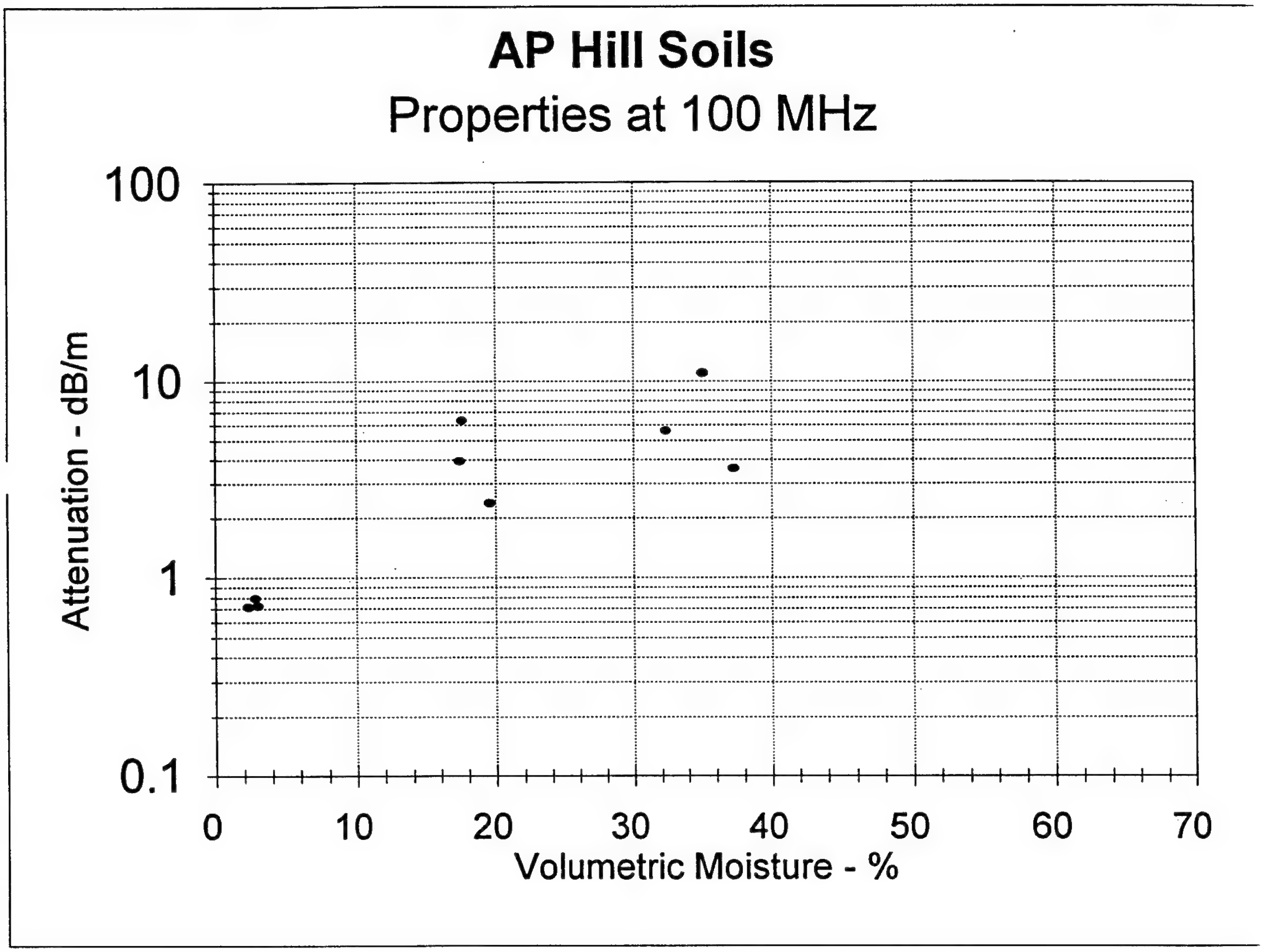


AP Hill Soils
Properties at 100 MHz
Imaginary Constant
50
40
30
20
10
0
0
10
20
30
40
50
60
70
Volumetric Moisture - %

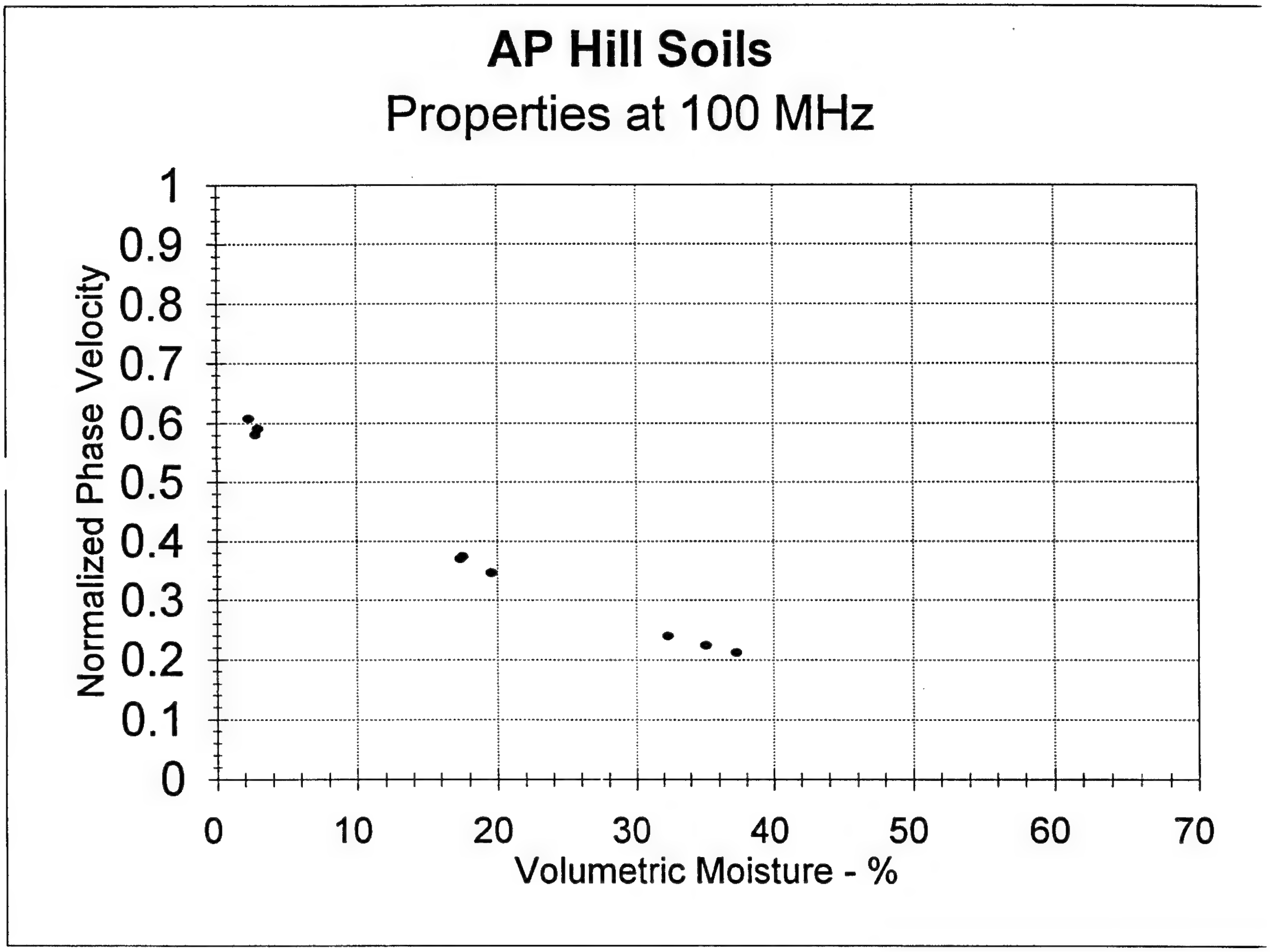

AP Hill Soils
Properties at 100 MHz
Conductivity - mho/m
1
0.1
0.01
0.001
0.0001
0
10
20
30
40
50
60
70
Volumetric Moisture - %



AP Hill Soils
Properties at 100 MHz
Loss Tangent
10
1
0.1
0.01
0.001
0
10
20
30
40
50
60
70
Volumetric Moisture - %



AP Hill Soils
Properties at 100 MHz
100
10
1
0.1
Attenuation - dB/m
0
10
20
30
40
50
60
70
Volumetric Moisture - %



AP Hill Soils
Properties at 100 MHz
Normalized Phase Velocity
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
10
20
30
40
50
60
70
Volumetric Moisture - %

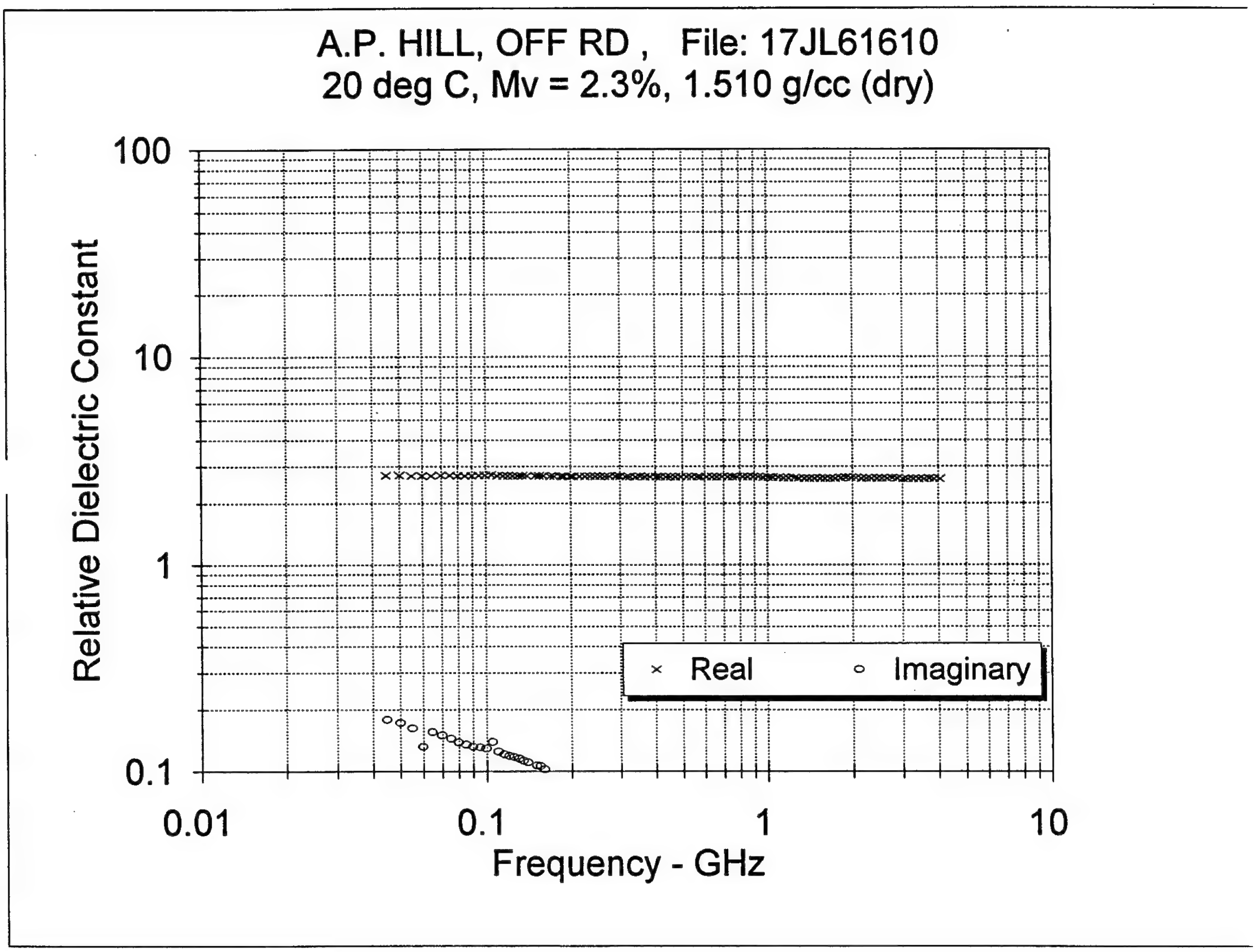
Fort A.P. Hill
Individual Sample Results

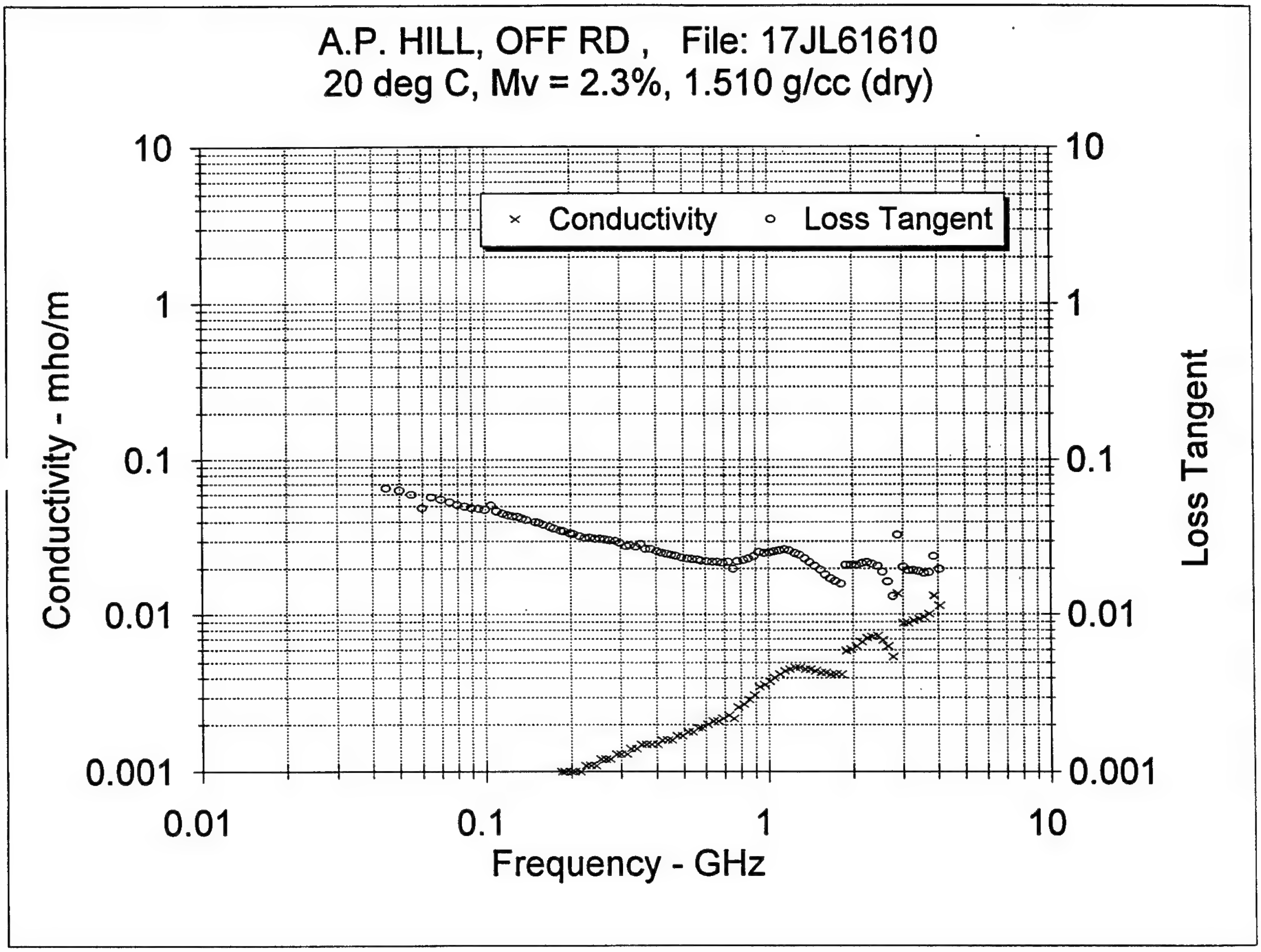
17JL61610
A.P. HILL, OFF RD
9.7
3
2.3
20
1.51

A.P. HILL, OFF RD , File: 17JL61610
20 deg C, Mv = 2.3%, 1.510 g/cc (dry)

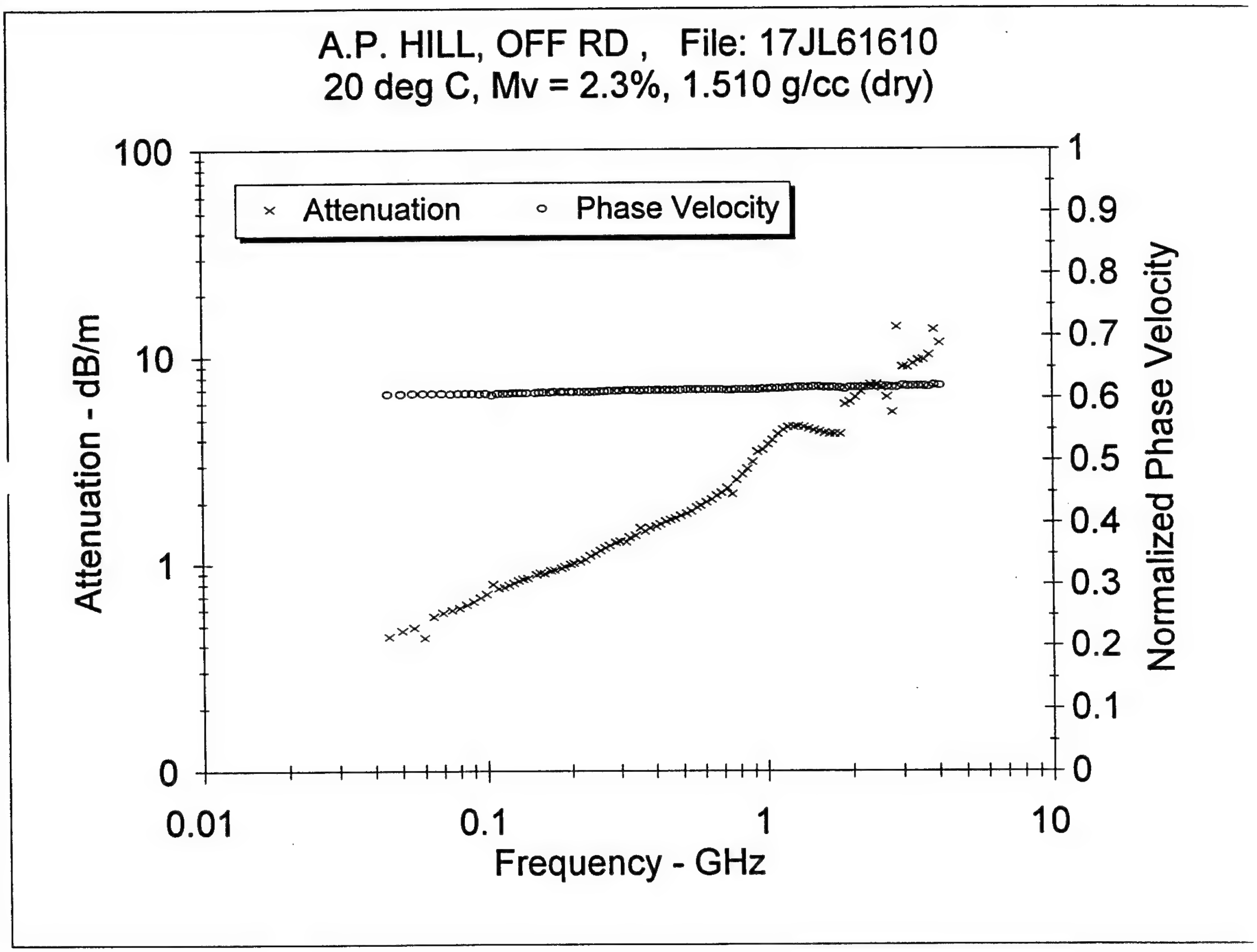
	ε'	ε''	σ	tan δ	attn	v/c
0.045	2.7065	0.1782	0.0004	0.0659	0.4432	0.6075
0.05	2.7103	0.1717	0.0005	0.0634	0.4742	0.6071
0.055	2.7023	0.1619	0.0005	0.0599	0.4925	0.608
0.06	2.7037	0.1322	0.0004	0.0489	0.4385	0.608
0.065	2.7051	0.1548	0.0006	0.0572	0.5564	0.6078
0.07	2.7067	0.1498	0.0006	0.0554	0.5796	0.6076
0.075	2.7088	0.1445	0.0006	0.0533	0.5986	0.6074
0.08	2.703	0.1382	0.0006	0.0511	0.6117	0.608
0.085	2.7056	0.135	0.0006	0.0499	0.6345	0.6078
0.09	2.7032	0.132	0.0007	0.0488	0.657	0.608
0.095	2.7083	0.1313	0.0007	0.0485	0.6892	0.6075
0.1	2.7067	0.1293	0.0007	0.0478	0.7144	0.6077
0.105	2.7232	0.1388	0.0008	0.051	0.8029	0.6058
0.11	2.7025	0.1256	0.0008	0.0465	0.7642	0.6081
0.115	2.7016	0.1214	0.0008	0.045	0.7727	0.6082
0.12	2.7045	0.1193	0.0008	0.0441	0.7918	0.6079
0.125	2.7009	0.1175	0.0008	0.0435	0.8129	0.6083
0.13	2.699	0.1154	0.0008	0.0428	0.8303	0.6086
0.135	2.6978	0.1132	0.0009	0.042	0.8464	0.6087
0.14	2.698	0.1105	0.0009	0.0409	0.8564	0.6087
0.15	2.6951	0.1072	0.0009	0.0398	0.8906	0.609
0.155	2.6935	0.1061	0.0009	0.0394	0.9115	0.6092
0.16	2.6925	0.1023	0.0009	0.038	0.907	0.6093
0.17	2.6906	0.0988	0.0009	0.0367	0.9317	0.6095
0.175	2.6887	0.0967	0.0009	0.036	0.9388	0.6098
0.185	2.6867	0.0937	0.001	0.0349	0.9619	0.61
0.19	2.6856	0.0929	0.001	0.0346	0.9797	0.6101
0.2	2.6839	0.0901	0.001	0.0336	1.0008	0.6103
0.205	2.6824	0.089	0.001	0.0332	1.0135	0.6105
0.215	2.6805	0.0864	0.001	0.0322	1.0319	0.6107
0.225	2.6793	0.0846	0.0011	0.0316	1.058	0.6108
0.235	2.6763	0.0844	0.0011	0.0315	1.1022	0.6112
0.245	2.6763	0.0829	0.0011	0.031	1.1297	0.6112
0.255	2.6735	0.0825	0.0012	0.0309	1.1705	0.6115
0.265	2.67	0.0819	0.0012	0.0307	1.2077	0.6119
0.275	2.6683	0.0809	0.0012	0.0303	1.2386	0.6121
0.29	2.6655	0.0794	0.0013	0.0298	1.2825	0.6124
0.3	2.6647	0.0775	0.0013	0.0291	1.2957	0.6125
0.315	2.6571	0.0733	0.0013	0.0276	1.2883	0.6134
0.325	2.6627	0.0747	0.0014	0.0281	1.3536	0.6128
0.34	2.661	0.073	0.0014	0.0274	1.3843	0.613
0.355	2.6653	0.0762	0.0015	0.0286	1.5068	0.6125
0.37	2.6598	0.0705	0.0015	0.0265	1.4554	0.6131
0.385	2.6604	0.0704	0.0015	0.0265	1.5114	0.613
0.405	2.6599	0.068	0.0015	0.0256	1.5357	0.6131
0.42	2.6602	0.067	0.0016	0.0252	1.5701	0.6131
0.44	2.6592	0.0658	0.0016	0.0248	1.6154	0.6132
0.455	2.659	0.0648	0.0016	0.0244	1.6457	0.6132
0.475	2.6581	0.0634	0.0017	0.0239	1.68	0.6133

0.495	2.657	0.0626	0.0017	0.0235	1.728	0.6134
0.52	2.6557	0.0612	0.0018	0.023	1.775	0.6136
0.54	2.6543	0.0604	0.0018	0.0228	1.8223	0.6138
0.565	2.6531	0.0599	0.0019	0.0226	1.8893	0.6139
0.585	2.6528	0.0591	0.0019	0.0223	1.9314	0.6139
0.61	2.653	0.059	0.002	0.0222	2.0099	0.6139
0.64	2.6543	0.0581	0.0021	0.0219	2.0761	0.6138
0.665	2.6555	0.058	0.0021	0.0218	2.1533	0.6136
0.695	2.6559	0.0573	0.0022	0.0216	2.2224	0.6136
0.725	2.6562	0.0579	0.0023	0.0218	2.3425	0.6135
0.755	2.6606	0.0523	0.0022	0.0197	2.2027	0.613
0.785	2.6542	0.0587	0.0026	0.0221	2.5732	0.6138
0.82	2.6531	0.0596	0.0027	0.0225	2.728	0.6139
0.855	2.6525	0.0606	0.0029	0.0229	2.8954	0.614
0.895	2.6533	0.0629	0.0031	0.0237	3.1414	0.6139
0.93	2.6539	0.0671	0.0035	0.0253	3.4818	0.6138
0.97	2.6456	0.066	0.0036	0.025	3.5814	0.6148
1.015	2.645	0.0668	0.0038	0.0252	3.7901	0.6148
1.055	2.6427	0.0675	0.004	0.0255	3.9814	0.6151
1.1	2.6395	0.0688	0.0042	0.026	4.2339	0.6155
1.15	2.6344	0.0693	0.0044	0.0263	4.4657	0.6161
1.195	2.6301	0.0683	0.0045	0.026	4.5781	0.6166
1.25	2.625	0.0657	0.0046	0.025	4.6088	0.6172
1.3	2.6219	0.0634	0.0046	0.0242	4.6262	0.6175
1.36	2.6197	0.0601	0.0045	0.023	4.5963	0.6178
1.415	2.6186	0.0568	0.0045	0.0217	4.5197	0.6179
1.475	2.6171	0.0536	0.0044	0.0205	4.4409	0.6181
1.54	2.6171	0.0506	0.0043	0.0194	4.3851	0.6181
1.605	2.6186	0.0478	0.0043	0.0182	4.3104	0.6179
1.675	2.6202	0.045	0.0042	0.0172	4.2391	0.6178
1.745	2.6228	0.0432	0.0042	0.0165	4.2381	0.6175
1.82	2.6274	0.0415	0.0042	0.0158	4.2368	0.6169
1.9	2.6475	0.0557	0.0059	0.021	5.913	0.6145
1.98	2.6233	0.0545	0.006	0.0208	6.0624	0.6174
2.065	2.6241	0.055	0.0063	0.021	6.376	0.6173
2.155	2.6212	0.0561	0.0067	0.0214	6.7918	0.6176
2.25	2.6187	0.0567	0.0071	0.0217	7.174	0.6179
2.345	2.6155	0.0554	0.0072	0.0212	7.3099	0.6183
2.445	2.6126	0.0536	0.0073	0.0205	7.3783	0.6186
2.55	2.6103	0.049	0.0069	0.0188	7.0297	0.6189
2.66	2.6123	0.0427	0.0063	0.0164	6.399	0.6187
2.775	2.6232	0.0347	0.0054	0.0132	5.4067	0.6174
2.89	2.6174	0.0856	0.0137	0.0327	13.8999	0.618
3.015	2.6046	0.0528	0.0088	0.0203	8.9695	0.6196
3.145	2.6087	0.0504	0.0088	0.0193	8.92	0.6191
3.28	2.6091	0.0504	0.0092	0.0193	9.3039	0.6191
3.42	2.6085	0.0497	0.0094	0.019	9.5656	0.6191
3.57	2.6094	0.0482	0.0096	0.0185	9.6976	0.619
3.72	2.6139	0.0486	0.0101	0.0186	10.1792	0.6185
3.88	2.598	0.0616	0.0133	0.0237	13.4875	0.6204
4.045	2.6024	0.0509	0.0114	0.0196	11.6081	0.6199


A.P. HILL, OFF RD , File: 17JL61610
20 deg C, Mv = 2.3%, 1.510 g/cc (dry)
Relative Dielectric Constant
100
10
1
0.1
0.01
0.1
1
10
Frequency - GHz
Real
Imaginary



A.P. HILL, OFF RD , File: 17JL61610
20 deg C, Mv = 2.3%, 1.510 g/cc (dry)
Conductivity
Loss Tangent
Conductivity - mho/m
Loss Tangent
Frequency - GHz
10
1
0.1
0.01
0.001
0.01
0.1
1
10



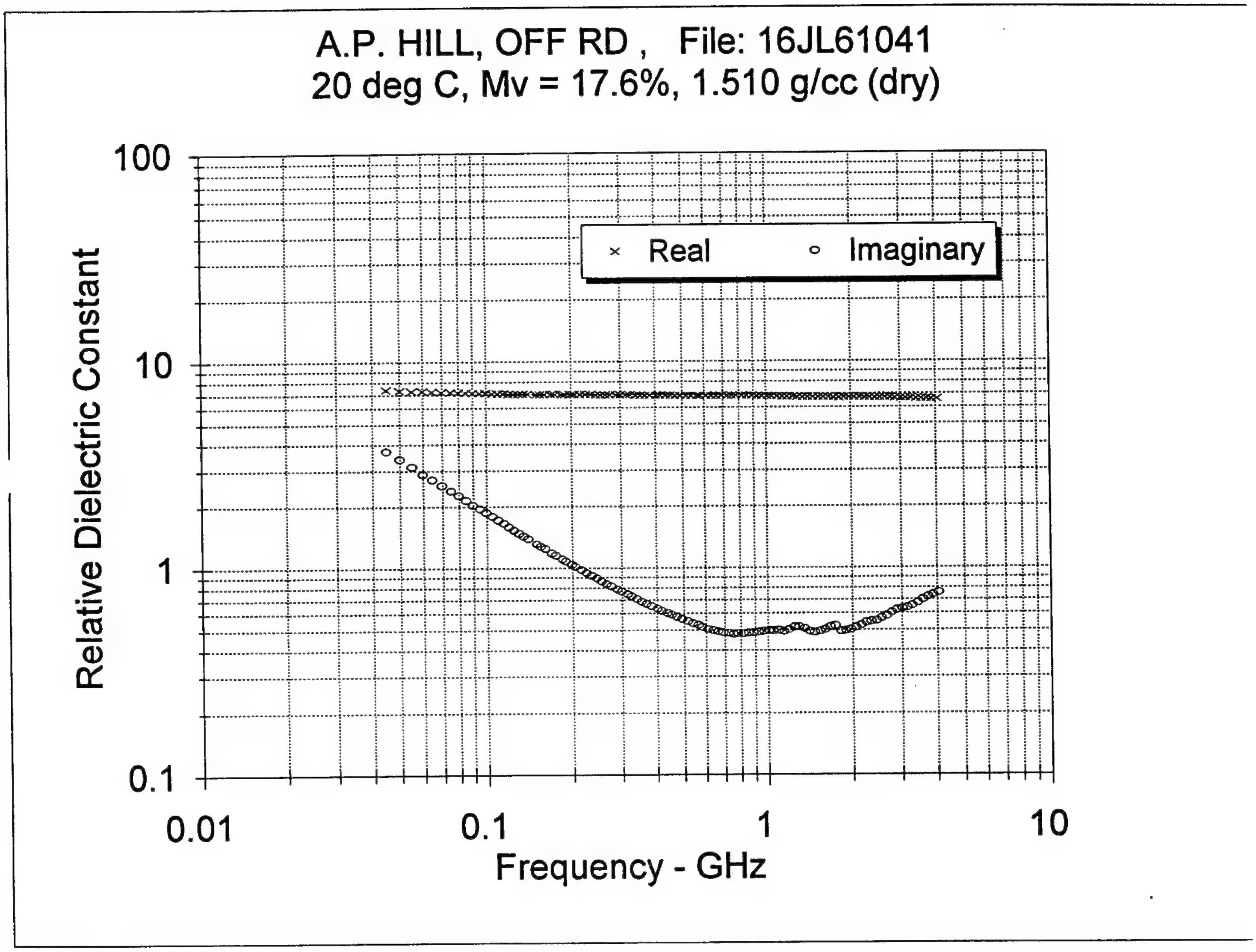
A.P. HILL, OFF RD , File: 17JL61610
20 deg C, Mv = 2.3%, 1.510 g/cc (dry)
Attenuation
Phase Velocity
Attenuation - dB/m
Normalized Phase Velocity
Frequency - GHz
100
10
1
0
0.01
0.1
1
10
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1

16JL61041
A.P. HILL, OFF RD
9.7
3
17.6
20
1.51

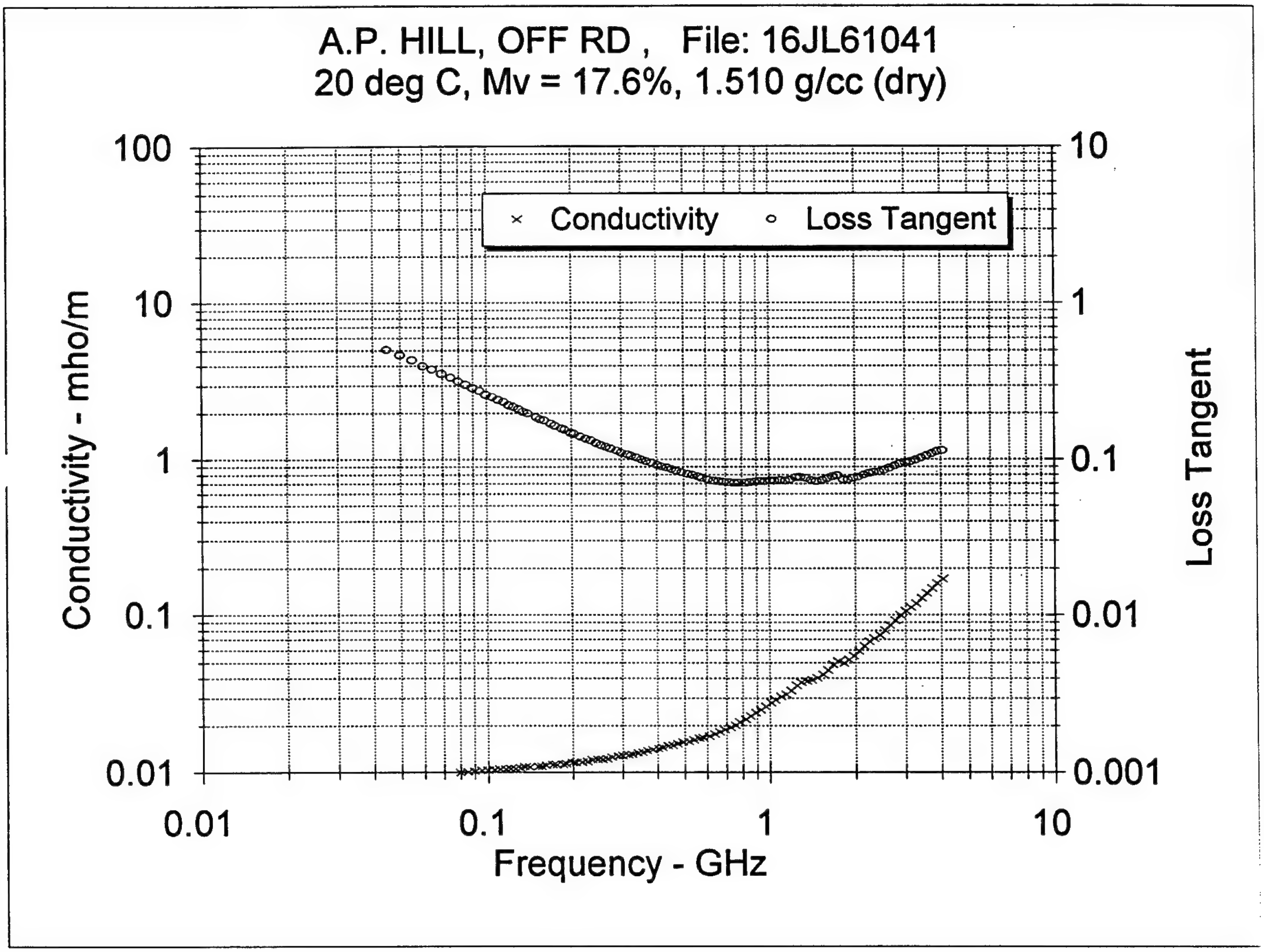
A.P. HILL, OFF RD , File: 16JL61041
20 deg C, Mv = 17.6%, 1.510 g/cc (dry)

0.045	7.3357	3.7083	0.0093	0.5055	5.4426	0.3586
0.05	7.278	3.3927	0.0094	0.4662	5.5771	0.3615
0.055	7.2321	3.1215	0.0095	0.4316	5.6816	0.3638
0.06	7.2322	2.8667	0.0096	0.3964	5.7104	0.365
0.065	7.1688	2.6993	0.0098	0.3765	5.8609	0.3672
0.07	7.1432	2.5282	0.0098	0.3539	5.9334	0.3686
0.075	7.1205	2.3823	0.0099	0.3346	6.0091	0.3698
0.08	7.0965	2.2539	0.01	0.3176	6.0822	0.3708
0.085	7.0761	2.1349	0.0101	0.3017	6.1369	0.3718
0.09	7.0643	2.0308	0.0102	0.2875	6.1925	0.3725
0.095	7.0565	1.9418	0.0103	0.2752	6.2586	0.373
0.1	7.0409	1.8532	0.0103	0.2632	6.2993	0.3737
0.105	7.0337	1.78	0.0104	0.2531	6.3599	0.3741
0.11	7.0196	1.709	0.0105	0.2435	6.4072	0.3747
0.115	7.0087	1.6453	0.0105	0.2348	6.4571	0.3752
0.12	6.9991	1.5814	0.0106	0.2259	6.4838	0.3756
0.125	6.9924	1.5303	0.0106	0.2188	6.5411	0.376
0.13	6.9839	1.4813	0.0107	0.2121	6.5915	0.3763
0.135	6.9766	1.4326	0.0108	0.2053	6.6255	0.3766
0.14	6.9732	1.3906	0.0108	0.1994	6.6729	0.3768
0.15	6.9604	1.3117	0.0109	0.1885	6.7538	0.3774
0.155	6.9558	1.2775	0.011	0.1837	6.8007	0.3776
0.16	6.9489	1.2438	0.0111	0.179	6.8399	0.3779
0.17	6.9397	1.183	0.0112	0.1705	6.9188	0.3782
0.175	6.9345	1.1545	0.0112	0.1665	6.9547	0.3784
0.185	6.9251	1.1022	0.0113	0.1592	7.026	0.3788
0.19	6.9218	1.0791	0.0114	0.1559	7.0671	0.379
0.2	6.9166	1.0367	0.0115	0.1499	7.1509	0.3792
0.205	6.9128	1.0159	0.0116	0.147	7.1857	0.3793
0.215	6.9068	0.9784	0.0117	0.1417	7.2625	0.3796
0.225	6.9014	0.9462	0.0118	0.1371	7.3539	0.3798
0.235	6.8959	0.9163	0.012	0.1329	7.4422	0.38
0.245	6.8907	0.8877	0.0121	0.1288	7.5207	0.3802
0.255	6.8848	0.8591	0.0122	0.1248	7.5795	0.3804
0.265	6.88	0.8364	0.0123	0.1216	7.6722	0.3805
0.275	6.8748	0.8151	0.0125	0.1186	7.7624	0.3807
0.29	6.8704	0.7861	0.0127	0.1144	7.8982	0.3809
0.3	6.8649	0.7661	0.0128	0.1116	7.9663	0.3811
0.315	6.8597	0.7425	0.013	0.1082	8.1103	0.3813
0.325	6.858	0.7272	0.0131	0.106	8.1974	0.3813
0.34	6.852	0.705	0.0133	0.1029	8.3184	0.3815
0.355	6.8478	0.6863	0.0135	0.1002	8.4579	0.3817
0.37	6.8435	0.6686	0.0138	0.0977	8.5909	0.3818
0.385	6.8395	0.6525	0.014	0.0954	8.7271	0.3819
0.405	6.8344	0.6326	0.0142	0.0926	8.9053	0.3821
0.42	6.831	0.6188	0.0145	0.0906	9.0357	0.3822
0.44	6.8255	0.6029	0.0148	0.0883	9.2263	0.3824
0.455	6.8226	0.5911	0.015	0.0866	9.3577	0.3825
0.475	6.8184	0.5775	0.0153	0.0847	9.5475	0.3826

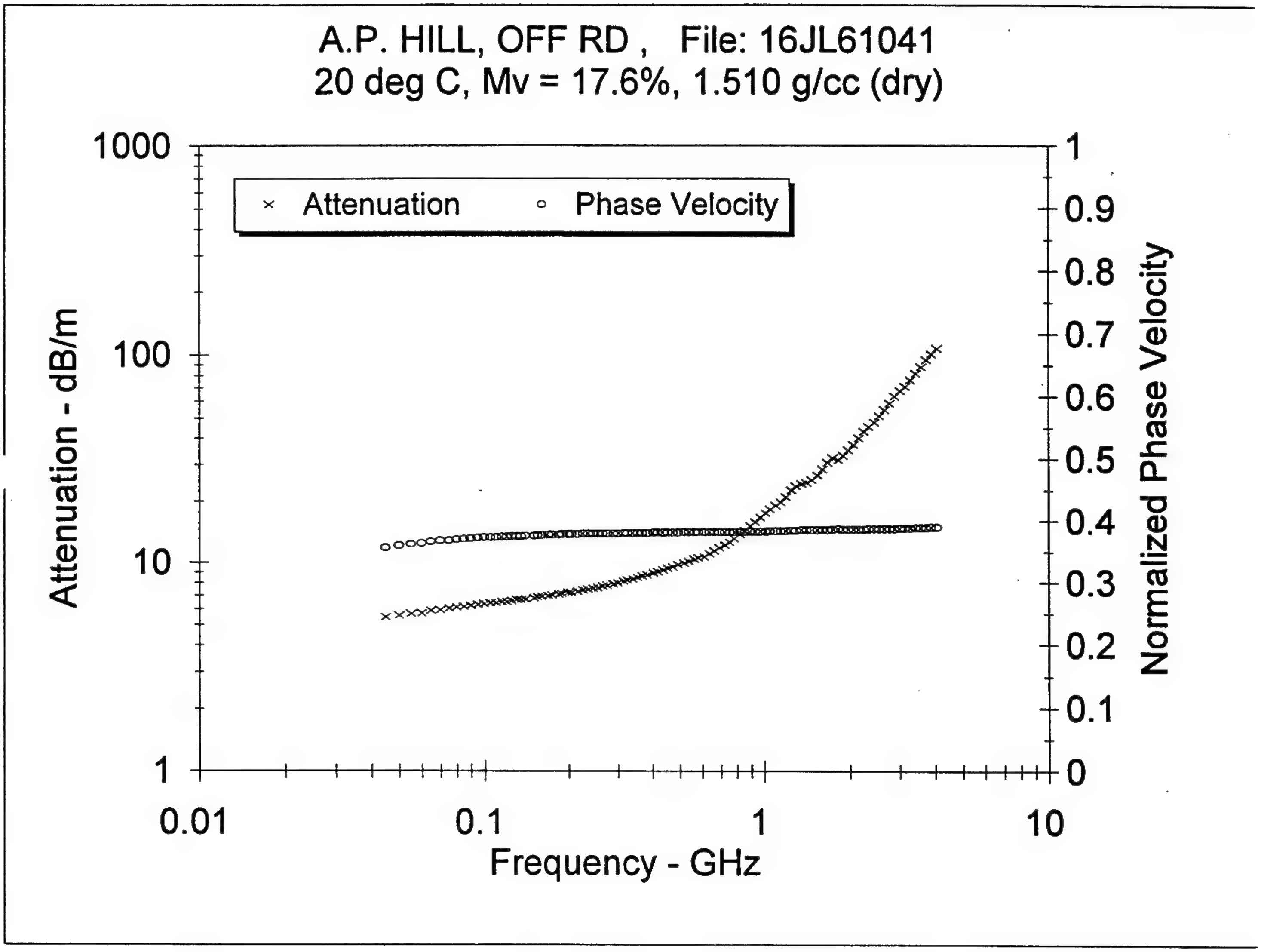
0.495	6.8144	0.565	0.0156	0.0829	9.7358	0.3827
0.52	6.8101	0.551	0.0159	0.0809	9.9778	0.3829
0.54	6.8068	0.5404	0.0162	0.0794	10.166	0.383
0.565	6.8017	0.5282	0.0166	0.0777	10.4012	0.3831
0.585	6.7974	0.5176	0.0168	0.0761	10.5553	0.3833
0.61	6.8002	0.5035	0.0171	0.074	10.7056	0.3832
0.64	6.8023	0.4968	0.0177	0.073	11.0821	0.3832
0.665	6.802	0.4922	0.0182	0.0724	11.4072	0.3832
0.695	6.8013	0.487	0.0188	0.0716	11.7973	0.3832
0.725	6.7999	0.4833	0.0195	0.0711	12.2137	0.3832
0.755	6.7989	0.4787	0.0201	0.0704	12.5993	0.3833
0.785	6.7984	0.4802	0.021	0.0706	13.1421	0.3833
0.82	6.7963	0.4805	0.0219	0.0707	13.7378	0.3833
0.855	6.7927	0.4828	0.023	0.0711	14.3958	0.3834
0.895	6.7867	0.4862	0.0242	0.0716	15.1828	0.3836
0.93	6.7799	0.488	0.0252	0.072	15.8429	0.3838
0.97	6.7737	0.4905	0.0265	0.0724	16.6186	0.384
1.015	6.7648	0.493	0.0278	0.0729	17.4892	0.3842
1.055	6.7576	0.4943	0.029	0.0732	18.2364	0.3844
1.1	6.7492	0.4956	0.0303	0.0734	19.0745	0.3847
1.15	6.7416	0.4915	0.0314	0.0729	19.7862	0.3849
1.195	6.7438	0.5005	0.0333	0.0742	20.9358	0.3848
1.25	6.7257	0.5139	0.0357	0.0764	22.5158	0.3853
1.3	6.7051	0.5163	0.0373	0.077	23.5594	0.3859
1.36	6.6839	0.5058	0.0383	0.0757	24.1855	0.3865
1.415	6.6788	0.492	0.0387	0.0737	24.4857	0.3867
1.475	6.6827	0.4861	0.0399	0.0727	25.2099	0.3866
1.54	6.6861	0.4911	0.0421	0.0734	26.5844	0.3865
1.605	6.6839	0.5026	0.0449	0.0752	28.3588	0.3865
1.675	6.6717	0.5175	0.0482	0.0776	30.5005	0.3869
1.745	6.644	0.5234	0.0508	0.0788	32.206	0.3877
1.82	6.6299	0.4915	0.0497	0.0741	31.5757	0.3881
1.9	6.6485	0.4931	0.0521	0.0742	33.0278	0.3876
1.98	6.6506	0.5027	0.0553	0.0756	35.08	0.3875
2.065	6.6506	0.5127	0.0589	0.0771	37.3167	0.3875
2.155	6.6477	0.5262	0.0631	0.0792	39.9739	0.3875
2.25	6.6393	0.5414	0.0677	0.0815	42.9642	0.3878
2.345	6.6255	0.5472	0.0713	0.0826	45.3016	0.3882
2.445	6.628	0.5499	0.0748	0.083	47.4593	0.3881
2.55	6.6251	0.5668	0.0804	0.0856	51.0335	0.3882
2.66	6.6205	0.5817	0.086	0.0879	54.6427	0.3883
2.775	6.6154	0.6006	0.0927	0.0908	58.8767	0.3884
2.89	6.6028	0.621	0.0998	0.094	63.4576	0.3887
3.015	6.5842	0.631	0.1058	0.0958	67.357	0.3893
3.145	6.5802	0.6376	0.1115	0.0969	71.0214	0.3894
3.28	6.5775	0.654	0.1193	0.0994	75.9906	0.3894
3.42	6.5726	0.6726	0.1279	0.1023	81.5013	0.3896
3.57	6.5661	0.6945	0.1379	0.1058	87.8929	0.3897
3.72	6.5539	0.7182	0.1486	0.1096	94.7847	0.39
3.88	6.5393	0.7372	0.159	0.1127	101.5743	0.3904
4.045	6.5256	0.7513	0.169	0.1151	108.0309	0.3908



A.P. HILL, OFF RD ,   File: 16JL61041
20 deg C, Mv = 17.6%, 1.510 g/cc (dry)
Real
Imaginary
Relative Dielectric Constant
100
10
1
0.1
0.01
0.1
1
10
Frequency - GHz



A.P. HILL, OFF RD , File: 16JL61041
20 deg C, Mv = 17.6%, 1.510 g/cc (dry)
Conductivity
Loss Tangent
Conductivity - mho/m
Loss Tangent
100
10
1
0.1
0.01
10
1
0.1
0.01
0.001
0.01
0.1
1
10
Frequency - GHz

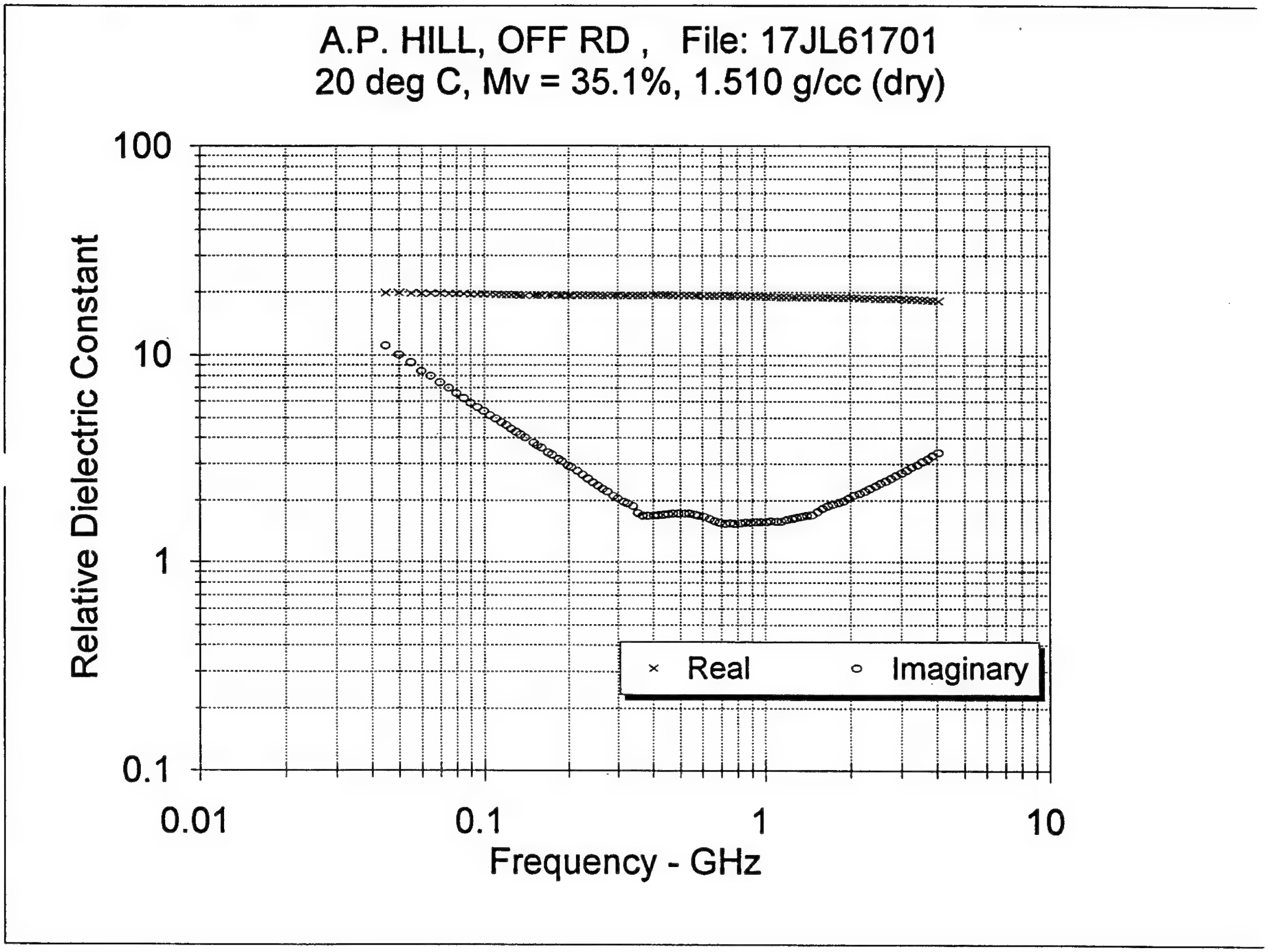

A.P. HILL, OFF RD , File: 16JL61041
20 deg C, Mv = 17.6%, 1.510 g/cc (dry)
Attenuation
Phase Velocity
Attenuation - dB/m
Normalized Phase Velocity
Frequency - GHz
1000
100
10
1
0.01
0.1
1
10
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0

17JL61701
A.P. HILL, OFF RD
9.7
3
35.1
20
1.51

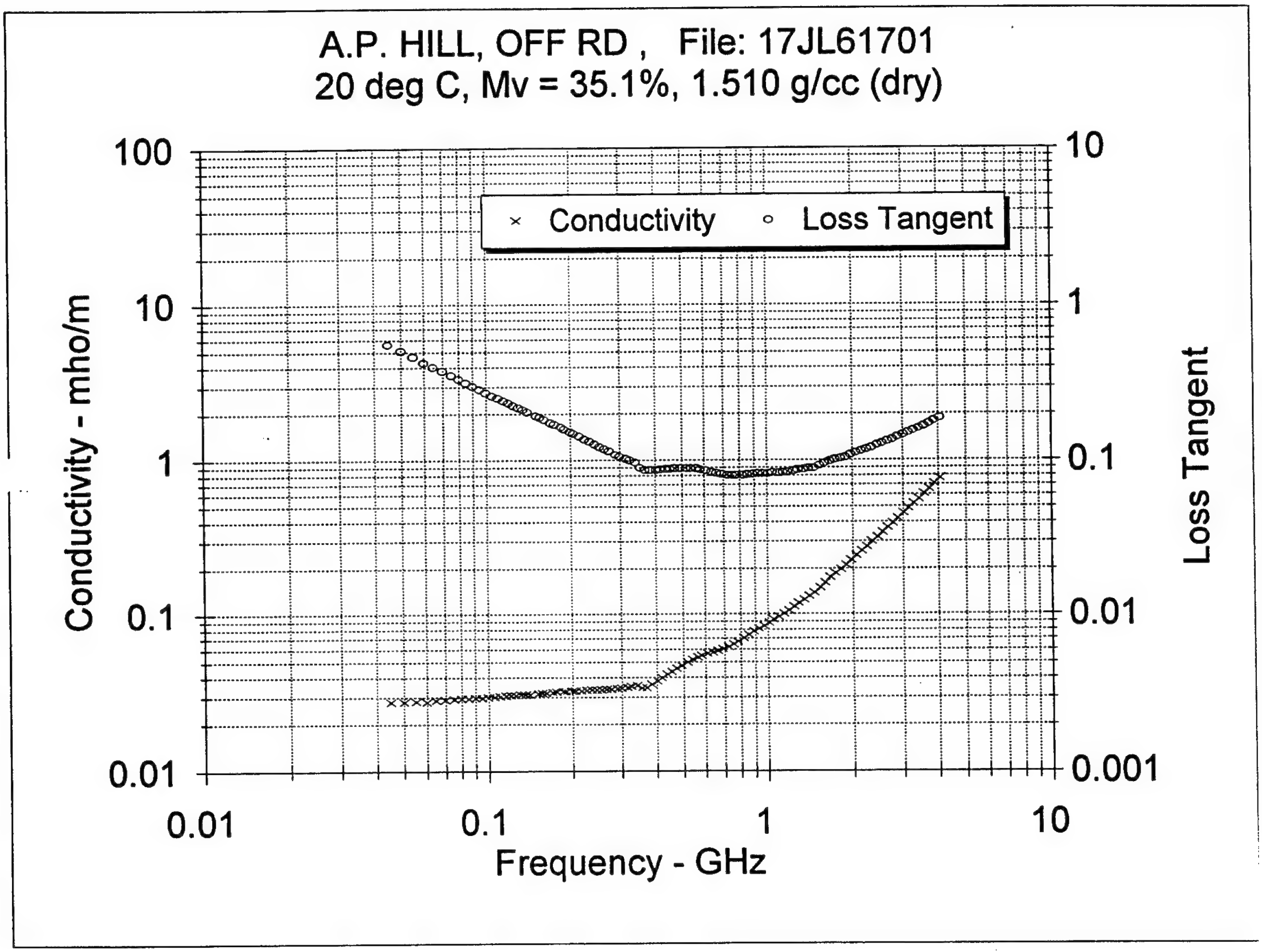
A.P. HILL, OFF RD , File: 17JL61701
20 deg C, Mv = 35.1%, 1.510 g/cc (dry)

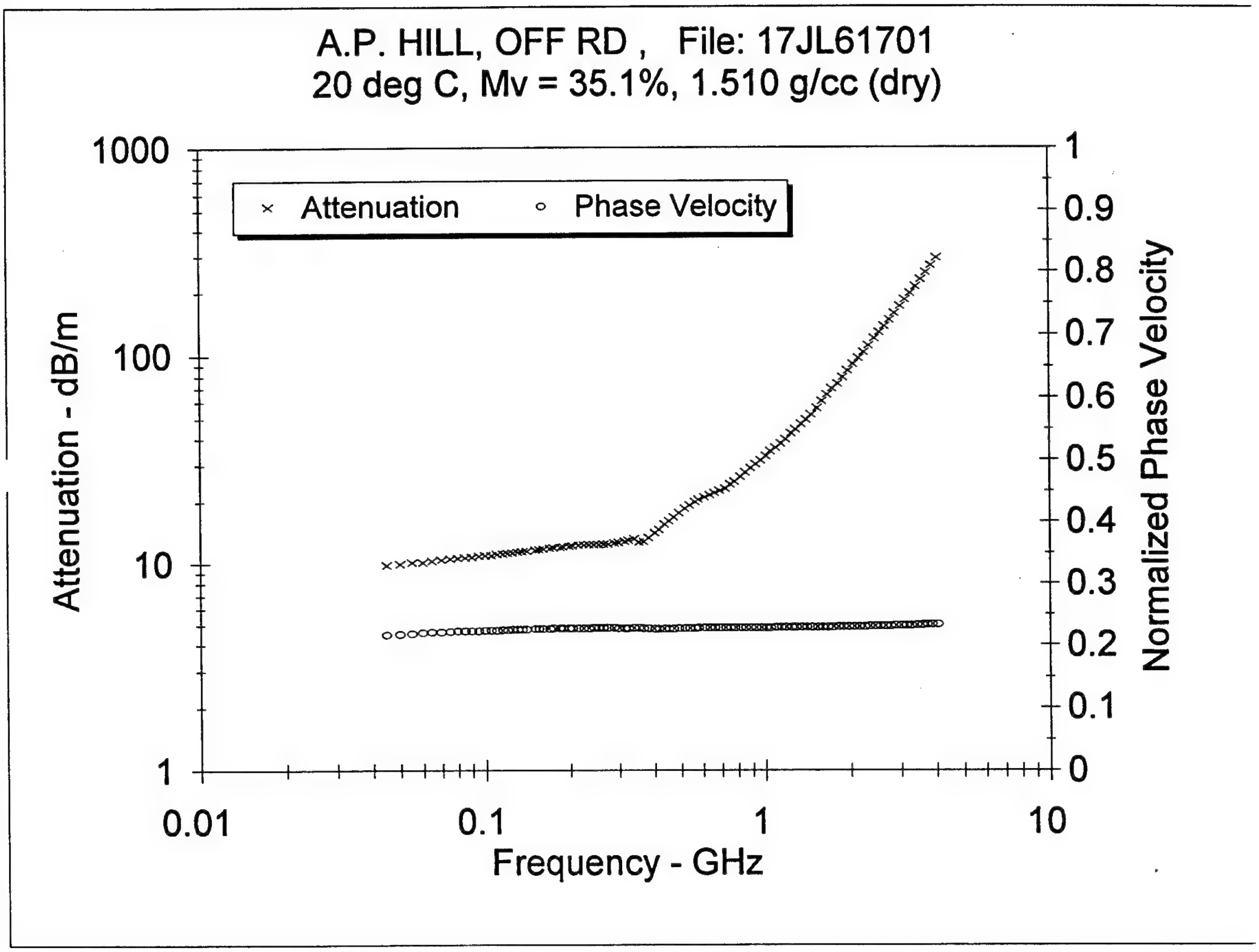
0.045	19.8122	11.0809	0.0277	0.5593	9.8376	0.2169
0.05	19.7959	10.0503	0.0279	0.5077	9.9747	0.2182
0.055	19.7486	9.2067	0.0282	0.4662	10.1066	0.2194
0.06	19.7283	8.3893	0.028	0.4252	10.0917	0.2204
0.065	19.6991	7.9044	0.0286	0.4013	10.3311	0.2211
0.07	19.6825	7.3887	0.0288	0.3754	10.4278	0.2217
0.075	19.648	6.9391	0.0289	0.3532	10.5214	0.2223
0.08	19.6255	6.5649	0.0292	0.3345	10.6394	0.2227
0.085	19.5856	6.2008	0.0293	0.3166	10.7027	0.2232
0.09	19.5609	5.8859	0.0295	0.3009	10.7758	0.2236
0.095	19.5461	5.6094	0.0296	0.287	10.8546	0.2239
0.1	19.5089	5.3602	0.0298	0.2748	10.9376	0.2243
0.105	19.478	5.1184	0.0299	0.2628	10.9835	0.2247
0.11	19.4722	4.931	0.0302	0.2532	11.0933	0.2248
0.115	19.4408	4.7347	0.0303	0.2435	11.1512	0.2252
0.12	19.4298	4.5727	0.0305	0.2353	11.2466	0.2253
0.125	19.4087	4.4061	0.0306	0.227	11.2997	0.2256
0.13	19.39	4.2578	0.0308	0.2196	11.3661	0.2258
0.135	19.3725	4.1216	0.0309	0.2128	11.4348	0.2259
0.14	19.352	3.9953	0.0311	0.2065	11.5047	0.2261
0.15	19.3234	3.7681	0.0314	0.195	11.6406	0.2264
0.155	19.3105	3.668	0.0316	0.19	11.716	0.2266
0.16	19.2954	3.5679	0.0317	0.1849	11.7709	0.2267
0.17	19.2698	3.3883	0.032	0.1758	11.89	0.2269
0.175	19.2549	3.3017	0.0321	0.1715	11.9335	0.2271
0.185	19.2306	3.1461	0.0324	0.1636	12.0323	0.2273
0.19	19.2226	3.0768	0.0325	0.1601	12.0896	0.2274
0.2	19.2068	2.938	0.0327	0.153	12.1601	0.2275
0.205	19.2034	2.8716	0.0327	0.1495	12.1849	0.2276
0.215	19.1889	2.7542	0.0329	0.1435	12.2642	0.2277
0.225	19.183	2.6374	0.033	0.1375	12.2948	0.2278
0.235	19.1795	2.5394	0.0332	0.1324	12.3675	0.2278
0.245	19.1776	2.437	0.0332	0.1271	12.3765	0.2279
0.255	19.1836	2.3459	0.0333	0.1223	12.4	0.2279
0.265	19.1829	2.2647	0.0334	0.1181	12.4418	0.2279
0.275	19.1901	2.1892	0.0335	0.1141	12.4799	0.2279
0.29	19.2047	2.0916	0.0337	0.1089	12.5713	0.2279
0.3	19.2155	2.0351	0.034	0.1059	12.6511	0.2278
0.315	19.2288	1.9679	0.0345	0.1023	12.8412	0.2277
0.325	19.2285	1.9285	0.0349	0.1003	12.9848	0.2278
0.34	19.2056	1.867	0.0353	0.0972	13.1598	0.2279
0.355	19.2046	1.7253	0.0341	0.0898	12.6996	0.228
0.37	19.3158	1.678	0.0345	0.0869	12.8375	0.2273
0.385	19.3602	1.6805	0.036	0.0868	13.3619	0.2271
0.405	19.3858	1.6857	0.038	0.087	14.0908	0.2269
0.42	19.3932	1.6909	0.0395	0.0872	14.655	0.2269
0.44	19.3883	1.7011	0.0416	0.0877	15.4465	0.2269
0.455	19.3801	1.7073	0.0432	0.0881	16.0346	0.2269
0.475	19.3621	1.715	0.0453	0.0886	16.8228	0.227

0.495	19.3373	1.7208	0.0474	0.089	17.6017	0.2272
0.52	19.304	1.7194	0.0497	0.0891	18.4917	0.2274
0.54	19.2745	1.7146	0.0515	0.089	19.1632	0.2276
0.565	19.2321	1.7002	0.0534	0.0884	19.9049	0.2278
0.585	19.2004	1.682	0.0547	0.0876	20.4054	0.228
0.61	19.1626	1.6544	0.0561	0.0863	20.9503	0.2282
0.64	19.1305	1.6141	0.0574	0.0844	21.4638	0.2284
0.665	19.1127	1.5846	0.0586	0.0829	21.9059	0.2285
0.695	19.1048	1.5533	0.06	0.0813	22.4473	0.2286
0.725	19.1103	1.5358	0.0619	0.0804	23.1495	0.2286
0.755	19.1181	1.5397	0.0646	0.0805	24.1632	0.2285
0.785	19.1134	1.533	0.0669	0.0802	25.0165	0.2286
0.82	19.1033	1.5387	0.0702	0.0805	26.2369	0.2286
0.855	19.0867	1.5478	0.0736	0.0811	27.5296	0.2287
0.895	19.0617	1.5577	0.0775	0.0817	29.0215	0.2289
0.93	19.0393	1.5622	0.0808	0.0821	30.2605	0.229
0.97	19.017	1.5619	0.0842	0.0821	31.5735	0.2291
1.015	19.0044	1.5649	0.0883	0.0823	33.1128	0.2292
1.055	18.9876	1.5812	0.0928	0.0833	34.7913	0.2293
1.1	18.9621	1.5717	0.0961	0.0829	36.0808	0.2294
1.15	18.9655	1.5751	0.1007	0.083	37.7996	0.2294
1.195	18.963	1.5937	0.1059	0.084	39.7443	0.2294
1.25	18.9517	1.6215	0.1127	0.0856	42.3097	0.2295
1.3	18.9359	1.6397	0.1185	0.0866	44.5156	0.2296
1.36	18.9197	1.6554	0.1252	0.0875	47.0344	0.2297
1.415	18.9114	1.6712	0.1315	0.0884	49.4143	0.2297
1.475	18.9282	1.6919	0.1388	0.0894	52.1223	0.2296
1.54	18.941	1.7468	0.1496	0.0922	56.1636	0.2295
1.605	18.9259	1.8122	0.1617	0.0958	60.7433	0.2296
1.675	18.8905	1.8683	0.174	0.0989	65.4125	0.2298
1.745	18.8583	1.9021	0.1846	0.1009	69.4321	0.23
1.82	18.8398	1.931	0.1954	0.1025	73.5532	0.2301
1.9	18.8362	1.976	0.2088	0.1049	78.5759	0.2301
1.98	18.8206	2.0402	0.2246	0.1084	84.5723	0.2302
2.065	18.7822	2.1007	0.2412	0.1118	90.9031	0.2304
2.155	18.7458	2.1508	0.2577	0.1147	97.215	0.2306
2.25	18.7185	2.2007	0.2753	0.1176	103.9222	0.2307
2.345	18.696	2.2675	0.2957	0.1213	111.6495	0.2309
2.445	18.6591	2.3383	0.3179	0.1253	120.151	0.2311
2.55	18.6198	2.4017	0.3406	0.129	128.8318	0.2313
2.66	18.594	2.4631	0.3643	0.1325	137.9048	0.2314
2.775	18.5757	2.5345	0.3911	0.1364	148.0896	0.2315
2.89	18.5571	2.612	0.4198	0.1408	159.0004	0.2316
3.015	18.5283	2.6972	0.4522	0.1456	171.3867	0.2317
3.145	18.4857	2.7835	0.4868	0.1506	184.6812	0.2319
3.28	18.4321	2.8665	0.5228	0.1555	198.5977	0.2322
3.42	18.3763	2.9518	0.5614	0.1606	213.5193	0.2325
3.57	18.3166	3.0499	0.6055	0.1665	230.6167	0.2329
3.72	18.2654	3.1537	0.6524	0.1727	248.7702	0.2331
3.88	18.2199	3.2747	0.7065	0.1797	269.676	0.2333
4.045	18.1824	3.3992	0.7646	0.1869	292.0353	0.2335



A.P. HILL, OFF RD , File: 17JL61701
20 deg C, Mv = 35.1%, 1.510 g/cc (dry)
100
10
1
0.1
Relative Dielectric Constant
0.01
0.1
1
10
Frequency - GHz
Real
Imaginary


A.P. HILL, OFF RD , File: 17JL61701
20 deg C, Mv = 35.1%, 1.510 g/cc (dry)
Conductivity
Loss Tangent
Conductivity - mho/m
Loss Tangent
Frequency - GHz
100
10
1
0.1
0.01
10
1
0.1
0.01
0.001
0.01
0.1
1
10

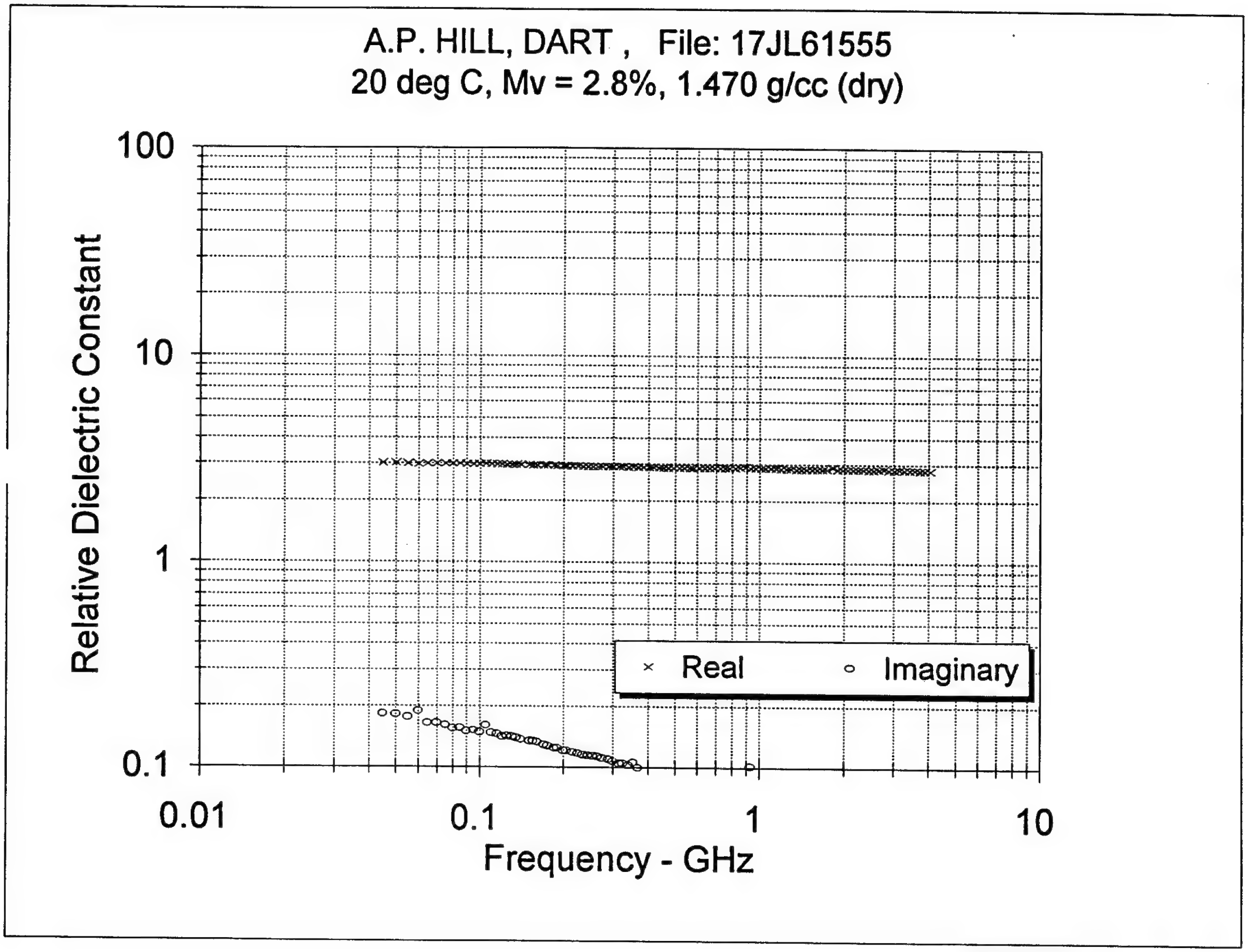

A.P. HILL, OFF RD , File: 17JL61701
20 deg C, Mv = 35.1%, 1.510 g/cc (dry)
Attenuation
Phase Velocity
Attenuation - dB/m
Normalized Phase Velocity
Frequency - GHz
1000
100
10
1
0.01
0.1
1
10
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9

17JL61555
A.P. HILL, DART
9.7
4
2.8
20
1.47

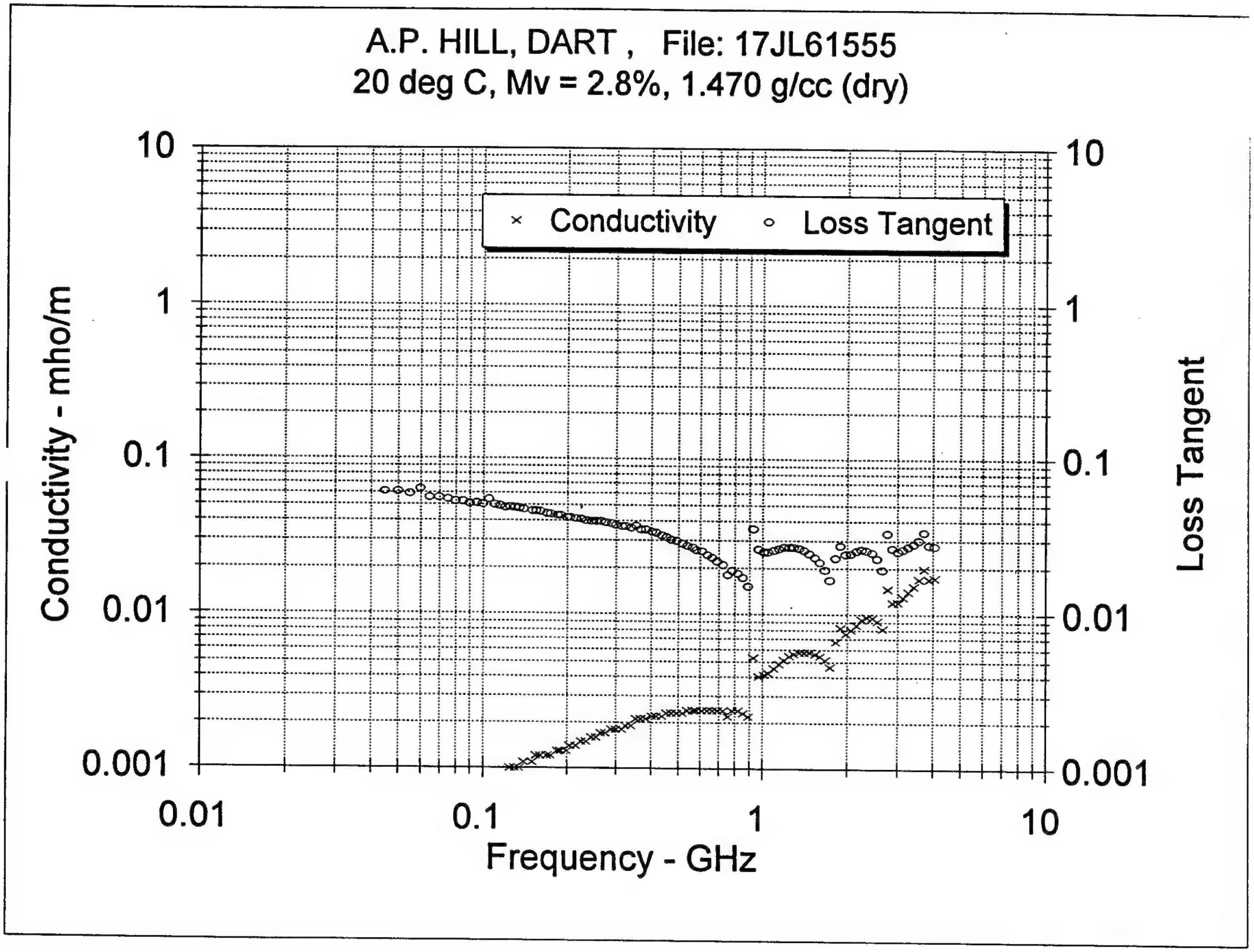
A.P. HILL, DART , File: 17JL61555
20 deg C, Mv = 2.8%, 1.470 g/cc (dry)

0.045	3.0009	0.1823	0.0005	0.0607	0.4305	0.577
0.05	2.9997	0.1814	0.0005	0.0605	0.476	0.5771
0.055	2.9861	0.1754	0.0005	0.0587	0.5076	0.5784
0.06	2.9698	0.188	0.0006	0.0633	0.5951	0.58
0.065	2.9805	0.1651	0.0006	0.0554	0.565	0.579
0.07	2.9795	0.1653	0.0006	0.0555	0.6095	0.5791
0.075	2.9784	0.1609	0.0007	0.054	0.6359	0.5792
0.08	2.9724	0.1552	0.0007	0.0522	0.655	0.5798
0.085	2.9718	0.1561	0.0007	0.0525	0.7	0.5799
0.09	2.9607	0.1506	0.0008	0.0509	0.7165	0.581
0.095	2.9694	0.1517	0.0008	0.0511	0.7606	0.5801
0.1	2.9602	0.1488	0.0008	0.0503	0.7866	0.581
0.105	2.9792	0.1608	0.0009	0.054	0.8896	0.5791
0.11	2.9585	0.148	0.0009	0.05	0.8606	0.5812
0.115	2.9561	0.1454	0.0009	0.0492	0.8844	0.5814
0.12	2.9567	0.142	0.0009	0.048	0.9011	0.5814
0.125	2.9525	0.143	0.001	0.0484	0.946	0.5818
0.13	2.9491	0.1421	0.001	0.0482	0.9783	0.5821
0.135	2.9471	0.1397	0.001	0.0474	0.9991	0.5823
0.14	2.9452	0.1375	0.0011	0.0467	1.0201	0.5825
0.15	2.9407	0.1353	0.0011	0.046	1.0759	0.583
0.155	2.9382	0.1346	0.0012	0.0458	1.1065	0.5832
0.16	2.9352	0.1332	0.0012	0.0454	1.1314	0.5835
0.17	2.9317	0.1294	0.0012	0.0441	1.1686	0.5839
0.175	2.9292	0.1281	0.0012	0.0437	1.1909	0.5841
0.185	2.9255	0.125	0.0013	0.0427	1.229	0.5845
0.19	2.924	0.1249	0.0013	0.0427	1.2616	0.5847
0.2	2.9195	0.1212	0.0013	0.0415	1.2902	0.5851
0.205	2.918	0.1212	0.0014	0.0415	1.3226	0.5853
0.215	2.914	0.1192	0.0014	0.0409	1.3651	0.5857
0.225	2.9127	0.1179	0.0015	0.0405	1.4139	0.5858
0.235	2.907	0.1158	0.0015	0.0398	1.4516	0.5864
0.245	2.9055	0.1147	0.0016	0.0395	1.4993	0.5865
0.255	2.9006	0.1141	0.0016	0.0393	1.5531	0.587
0.265	2.8975	0.1138	0.0017	0.0393	1.6106	0.5874
0.275	2.8934	0.1118	0.0017	0.0386	1.6437	0.5878
0.29	2.8892	0.1098	0.0018	0.038	1.7042	0.5882
0.3	2.8874	0.1081	0.0018	0.0374	1.7349	0.5884
0.315	2.8806	0.1048	0.0018	0.0364	1.7693	0.5891
0.325	2.8816	0.105	0.0019	0.0364	1.8278	0.589
0.34	2.8782	0.1031	0.0019	0.0358	1.8782	0.5893
0.355	2.8816	0.1061	0.0021	0.0368	2.0175	0.589
0.37	2.8753	0.1004	0.0021	0.0349	1.9924	0.5897
0.385	2.8734	0.0999	0.0021	0.0348	2.0631	0.5898
0.405	2.8701	0.0974	0.0022	0.0339	2.1181	0.5902
0.42	2.8681	0.0951	0.0022	0.0332	2.1451	0.5904
0.44	2.8647	0.0916	0.0022	0.032	2.1669	0.5908
0.455	2.8632	0.0894	0.0023	0.0312	2.1867	0.5909
0.475	2.8614	0.0861	0.0023	0.0301	2.1989	0.5911

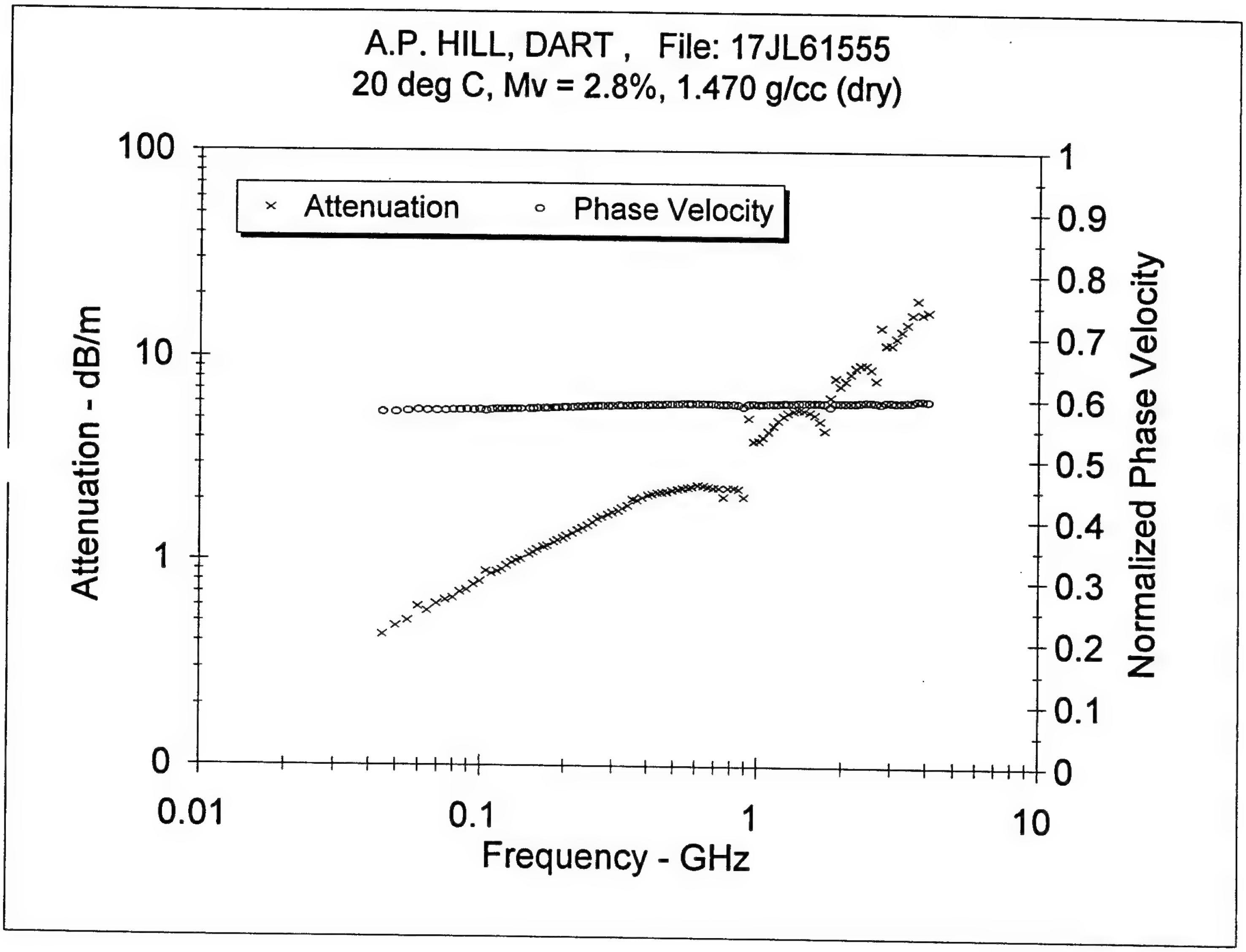
0.495	2.8591	0.0842	0.0023	0.0295	2.2419	0.5913
0.52	2.8567	0.0809	0.0023	0.0283	2.2648	0.5916
0.54	2.8548	0.0785	0.0024	0.0275	2.2821	0.5918
0.565	2.8532	0.076	0.0024	0.0267	2.3135	0.592
0.585	2.8525	0.074	0.0024	0.0259	2.33	0.592
0.61	2.8518	0.0721	0.0024	0.0253	2.3694	0.5921
0.64	2.8521	0.0683	0.0024	0.0239	2.3538	0.5921
0.665	2.8539	0.0653	0.0024	0.0229	2.3383	0.5919
0.695	2.8548	0.0619	0.0024	0.0217	2.3142	0.5918
0.725	2.8561	0.0591	0.0024	0.0207	2.3075	0.5917
0.755	2.8622	0.0513	0.0022	0.0179	2.083	0.5911
0.785	2.8585	0.0547	0.0024	0.0191	2.308	0.5914
0.82	2.861	0.0524	0.0024	0.0183	2.3093	0.5912
0.855	2.8669	0.0494	0.0023	0.0172	2.2693	0.5906
0.895	2.9027	0.0435	0.0022	0.015	2.0783	0.5869
0.93	2.857	0.1018	0.0053	0.0356	5.0916	0.5915
0.97	2.8527	0.0747	0.004	0.0262	3.9038	0.592
1.015	2.8558	0.0718	0.0041	0.0251	3.9205	0.5917
1.055	2.8561	0.0719	0.0042	0.0252	4.08	0.5917
1.1	2.8551	0.0739	0.0045	0.0259	4.3748	0.5918
1.15	2.8522	0.0754	0.0048	0.0264	4.6709	0.5921
1.195	2.8488	0.0768	0.0051	0.027	4.9469	0.5924
1.25	2.844	0.0773	0.0054	0.0272	5.2112	0.5929
1.3	2.8395	0.077	0.0056	0.0271	5.4027	0.5934
1.36	2.8355	0.0753	0.0057	0.0265	5.5278	0.5938
1.415	2.8324	0.073	0.0057	0.0258	5.5801	0.5941
1.475	2.8287	0.0696	0.0057	0.0246	5.5519	0.5945
1.54	2.8267	0.0657	0.0056	0.0233	5.4753	0.5947
1.605	2.8268	0.0609	0.0054	0.0216	5.2898	0.5947
1.675	2.8288	0.0545	0.0051	0.0193	4.9351	0.5945
1.745	2.8351	0.047	0.0046	0.0166	4.4287	0.5939
1.82	2.8951	0.0664	0.0067	0.0229	6.4625	0.5877
1.9	2.8285	0.0781	0.0083	0.0276	8.0245	0.5945
1.98	2.8308	0.0686	0.0076	0.0242	7.344	0.5943
2.065	2.833	0.0697	0.008	0.0246	7.7725	0.5941
2.155	2.8311	0.0721	0.0086	0.0255	8.402	0.5943
2.25	2.8277	0.0741	0.0093	0.0262	9.0146	0.5946
2.345	2.8231	0.0733	0.0096	0.0259	9.2982	0.5951
2.445	2.8193	0.0701	0.0095	0.0249	9.2865	0.5955
2.55	2.8181	0.0642	0.0091	0.0228	8.8758	0.5957
2.66	2.8237	0.0545	0.0081	0.0193	7.84	0.5951
2.775	2.8403	0.0948	0.0146	0.0334	14.2034	0.5933
2.89	2.8162	0.0746	0.012	0.0265	11.6842	0.5958
3.015	2.8198	0.0713	0.012	0.0253	11.6472	0.5955
3.145	2.821	0.0737	0.0129	0.0261	12.5576	0.5953
3.28	2.82	0.0769	0.014	0.0273	13.6669	0.5954
3.42	2.8183	0.0796	0.0151	0.0282	14.7508	0.5956
3.57	2.8186	0.0846	0.0168	0.03	16.3691	0.5956
3.72	2.7938	0.0948	0.0196	0.0339	19.1822	0.5982
3.88	2.7978	0.078	0.0168	0.0279	16.4575	0.5978
4.045	2.7985	0.0767	0.0172	0.0274	16.858	0.5977



A.P. HILL, DART , File: 17JL61555
20 deg C, Mv = 2.8%, 1.470 g/cc (dry)
100
10
1
0.1
Relative Dielectric Constant
0.01
0.1
1
10
Frequency - GHz
Real
Imaginary



A.P. HILL, DART , File: 17JL61555
20 deg C, Mv = 2.8%, 1.470 g/cc (dry)
Conductivity
Loss Tangent
Conductivity - mho/m
Loss Tangent
10
1
0.1
0.01
0.001
0.01
0.1
1
10
Frequency - GHz

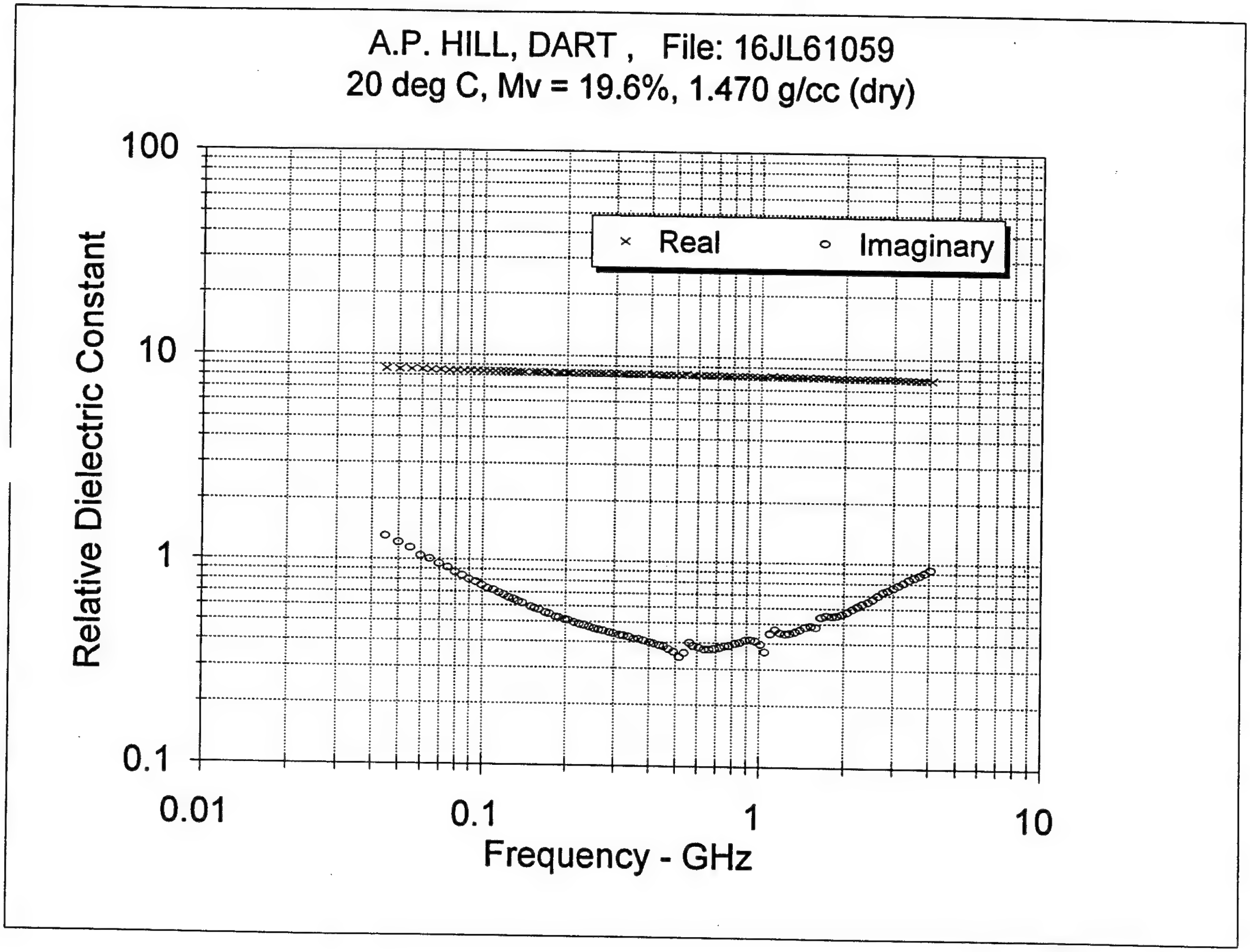

A.P. HILL, DART , File: 17JL61555
20 deg C, Mv = 2.8%, 1.470 g/cc (dry)
Attenuation
Phase Velocity
100
10
1
0
Attenuation - dB/m
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Normalized Phase Velocity
0.01
0.1
1
10
Frequency - GHz

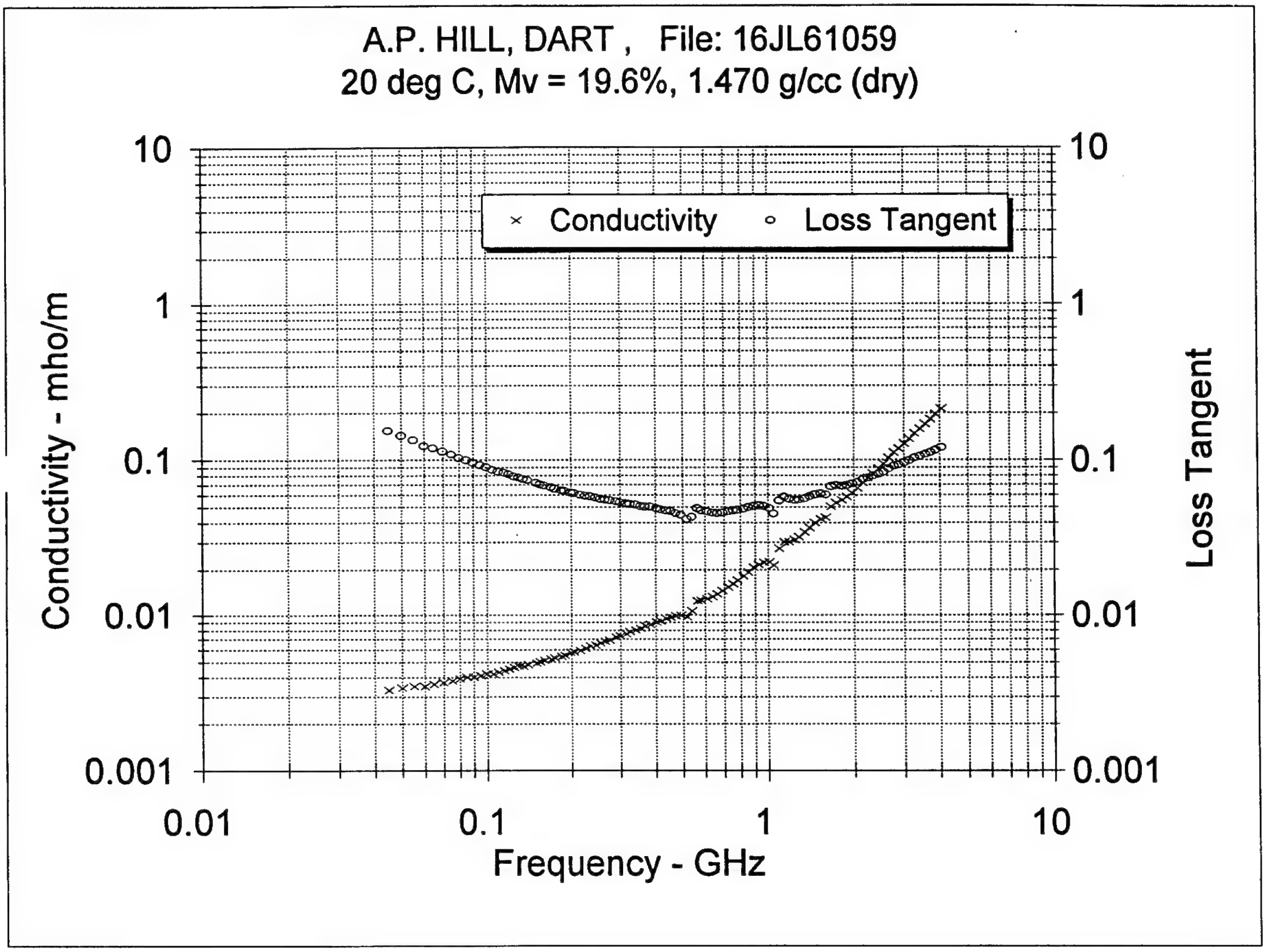
16JL61059
A.P. HILL, DART
9.7
4
19.6
20
1.47

A.P. HILL, DART , File: 16JL61059
20 deg C, Mv = 19.6%, 1.470 g/cc (dry)

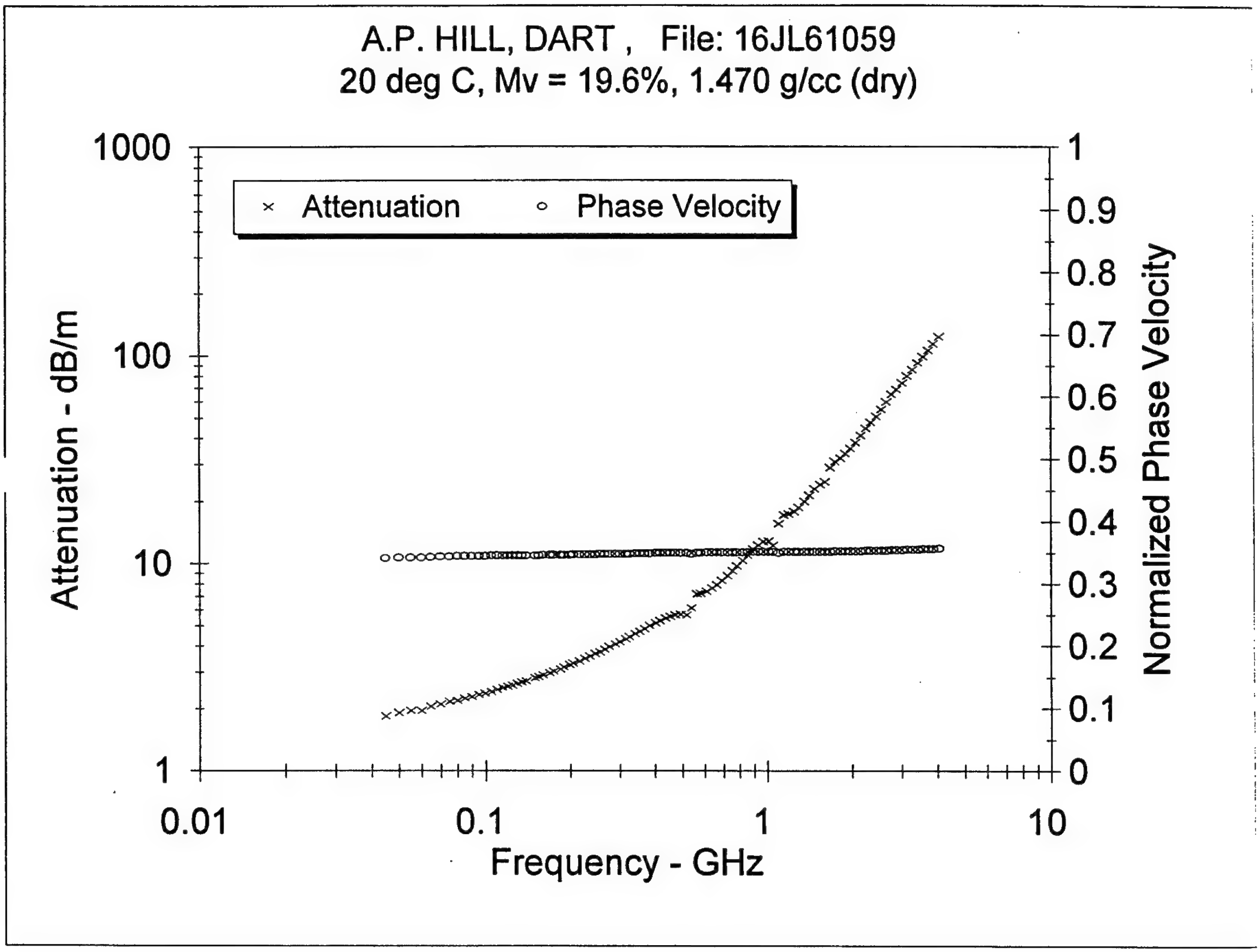
0.045	8.4837	1.3059	0.0033	0.1539	1.8298	0.3423
0.05	8.4618	1.2149	0.0034	0.1436	1.8946	0.3429
0.055	8.4399	1.1369	0.0035	0.1347	1.9534	0.3434
0.06	8.472	1.0426	0.0035	0.1231	1.9513	0.3429
0.065	8.4115	1.006	0.0036	0.1196	2.0472	0.3442
0.07	8.4019	0.9543	0.0037	0.1136	2.0928	0.3444
0.075	8.39	0.914	0.0038	0.1089	2.1496	0.3447
0.08	8.3706	0.8708	0.0039	0.104	2.1871	0.3452
0.085	8.3704	0.8392	0.004	0.1003	2.2399	0.3452
0.09	8.3566	0.8064	0.004	0.0965	2.281	0.3455
0.095	8.3557	0.7798	0.0041	0.0933	2.3286	0.3456
0.1	8.347	0.7527	0.0042	0.0902	2.3673	0.3458
0.105	8.3227	0.7237	0.0042	0.087	2.3937	0.3463
0.11	8.3304	0.7101	0.0043	0.0852	2.4593	0.3462
0.115	8.3223	0.6925	0.0044	0.0832	2.5086	0.3463
0.12	8.3152	0.6761	0.0045	0.0813	2.5571	0.3465
0.125	8.3093	0.6552	0.0046	0.0789	2.5823	0.3466
0.13	8.3027	0.6438	0.0047	0.0775	2.6399	0.3468
0.135	8.2994	0.6274	0.0047	0.0756	2.6723	0.3469
0.14	8.2945	0.6162	0.0048	0.0743	2.7229	0.347
0.15	8.2836	0.5905	0.0049	0.0713	2.7976	0.3472
0.155	8.2808	0.5813	0.005	0.0702	2.8464	0.3473
0.16	8.2753	0.573	0.0051	0.0692	2.8971	0.3474
0.17	8.2675	0.5535	0.0052	0.067	2.9751	0.3476
0.175	8.2618	0.5456	0.0053	0.066	3.0196	0.3477
0.185	8.252	0.5293	0.0054	0.0641	3.0988	0.3479
0.19	8.2527	0.5249	0.0055	0.0636	3.1559	0.3479
0.2	8.2451	0.5131	0.0057	0.0622	3.249	0.3481
0.205	8.2411	0.5083	0.0058	0.0617	3.3003	0.3482
0.215	8.2359	0.4961	0.0059	0.0602	3.3793	0.3483
0.225	8.2285	0.4888	0.0061	0.0594	3.4858	0.3485
0.235	8.2252	0.4809	0.0063	0.0585	3.5825	0.3485
0.245	8.2177	0.4727	0.0064	0.0575	3.6731	0.3487
0.255	8.2104	0.4637	0.0066	0.0565	3.7518	0.3489
0.265	8.2045	0.46	0.0068	0.0561	3.869	0.349
0.275	8.2	0.4542	0.0069	0.0554	3.9661	0.3491
0.29	8.1914	0.4454	0.0072	0.0544	4.1035	0.3493
0.3	8.1866	0.4399	0.0073	0.0537	4.1943	0.3494
0.315	8.1789	0.4338	0.0076	0.053	4.3444	0.3495
0.325	8.1747	0.4289	0.0078	0.0525	4.4329	0.3496
0.34	8.168	0.4244	0.008	0.052	4.5908	0.3498
0.355	8.1556	0.4159	0.0082	0.051	4.701	0.3501
0.37	8.1537	0.4134	0.0085	0.0507	4.8706	0.3501
0.385	8.1475	0.408	0.0087	0.0501	5.0042	0.3502
0.405	8.1402	0.4008	0.009	0.0492	5.1739	0.3504
0.42	8.1352	0.3956	0.0092	0.0486	5.2974	0.3505
0.44	8.1266	0.3885	0.0095	0.0478	5.4525	0.3507
0.455	8.1228	0.3826	0.0097	0.0471	5.5539	0.3508
0.475	8.1178	0.3738	0.0099	0.046	5.6661	0.3509

0.495	8.1144	0.3623	0.01	0.0446	5.7246	0.351
0.52	8.1221	0.3405	0.0098	0.0419	5.6495	0.3508
0.54	8.1846	0.3557	0.0107	0.0435	6.1059	0.3495
0.565	8.1226	0.3992	0.0125	0.0491	7.1958	0.3508
0.585	8.1088	0.3868	0.0126	0.0477	7.2256	0.3511
0.61	8.1038	0.3783	0.0128	0.0467	7.3709	0.3512
0.64	8.102	0.3739	0.0133	0.0461	7.6442	0.3512
0.665	8.1012	0.3728	0.0138	0.046	7.9209	0.3512
0.695	8.1008	0.3741	0.0145	0.0462	8.3063	0.3513
0.725	8.1009	0.3787	0.0153	0.0468	8.7728	0.3512
0.755	8.0958	0.3843	0.0161	0.0475	9.2728	0.3514
0.785	8.0949	0.3886	0.017	0.048	9.75	0.3514
0.82	8.0898	0.3965	0.0181	0.049	10.3933	0.3515
0.855	8.0815	0.4041	0.0192	0.05	11.0512	0.3517
0.895	8.0695	0.4111	0.0205	0.0509	11.7772	0.3519
0.93	8.0577	0.4134	0.0214	0.0513	12.3139	0.3522
0.97	8.044	0.4103	0.0221	0.051	12.76	0.3525
1.015	8.0328	0.3958	0.0223	0.0493	12.8905	0.3527
1.055	8.0481	0.3631	0.0213	0.0451	12.2774	0.3524
1.1	8.1216	0.4458	0.0273	0.0549	15.6471	0.3508
1.15	8.0429	0.4657	0.0298	0.0579	17.1708	0.3525
1.195	8.0247	0.4519	0.03	0.0563	17.3342	0.3529
1.25	8.0219	0.4449	0.0309	0.0555	17.8533	0.3529
1.3	8.024	0.4467	0.0323	0.0557	18.6417	0.3529
1.36	8.0258	0.4567	0.0345	0.0569	19.9351	0.3528
1.415	8.0235	0.4696	0.0369	0.0585	21.3287	0.3529
1.475	8.0155	0.4824	0.0396	0.0602	22.8498	0.3531
1.54	8.0053	0.4876	0.0418	0.0609	24.1294	0.3533
1.605	8.0171	0.4821	0.043	0.0601	24.8435	0.353
1.675	8.0223	0.5407	0.0504	0.0674	29.0666	0.3529
1.745	7.9849	0.55	0.0534	0.0689	30.8774	0.3537
1.82	7.9709	0.5478	0.0554	0.0687	32.1019	0.354
1.9	7.9675	0.551	0.0582	0.0692	33.7178	0.3541
1.98	7.9675	0.5603	0.0617	0.0703	35.7293	0.3541
2.065	7.9666	0.5753	0.0661	0.0722	38.2611	0.3541
2.155	7.9641	0.5954	0.0713	0.0748	41.3236	0.3541
2.25	7.9538	0.6145	0.0769	0.0773	44.5623	0.3543
2.345	7.9478	0.6288	0.082	0.0791	47.5358	0.3544
2.445	7.9442	0.6465	0.0879	0.0814	50.9693	0.3545
2.55	7.9402	0.6685	0.0948	0.0842	54.9792	0.3546
2.66	7.9347	0.6956	0.1029	0.0877	59.6871	0.3547
2.775	7.9156	0.7246	0.1118	0.0915	64.9426	0.3551
2.89	7.9019	0.7375	0.1185	0.0933	68.8952	0.3554
3.015	7.8952	0.7597	0.1274	0.0962	74.0609	0.3555
3.145	7.8834	0.7857	0.1374	0.0997	79.9558	0.3557
3.28	7.8714	0.8098	0.1477	0.1029	86.0005	0.356
3.42	7.8547	0.8357	0.1589	0.1064	92.6263	0.3563
3.57	7.8403	0.8552	0.1698	0.1091	99.0358	0.3566
3.72	7.8316	0.8787	0.1818	0.1122	106.0771	0.3568
3.88	7.822	0.908	0.1959	0.1161	114.3894	0.357
4.045	7.8106	0.9412	0.2117	0.1205	123.6841	0.3572


A.P. HILL, DART , File: 16JL61059
20 deg C, Mv = 19.6%, 1.470 g/cc (dry)
Real
Imaginary
Relative Dielectric Constant
100
10
1
0.1
0.01
0.1
1
10
Frequency - GHz



A.P. HILL, DART , File: 16JL61059
20 deg C, Mv = 19.6%, 1.470 g/cc (dry)
Conductivity
Loss Tangent
Conductivity - mho/m
Loss Tangent
Frequency - GHz
10
1
0.1
0.01
0.001
0.01
0.1
1
10



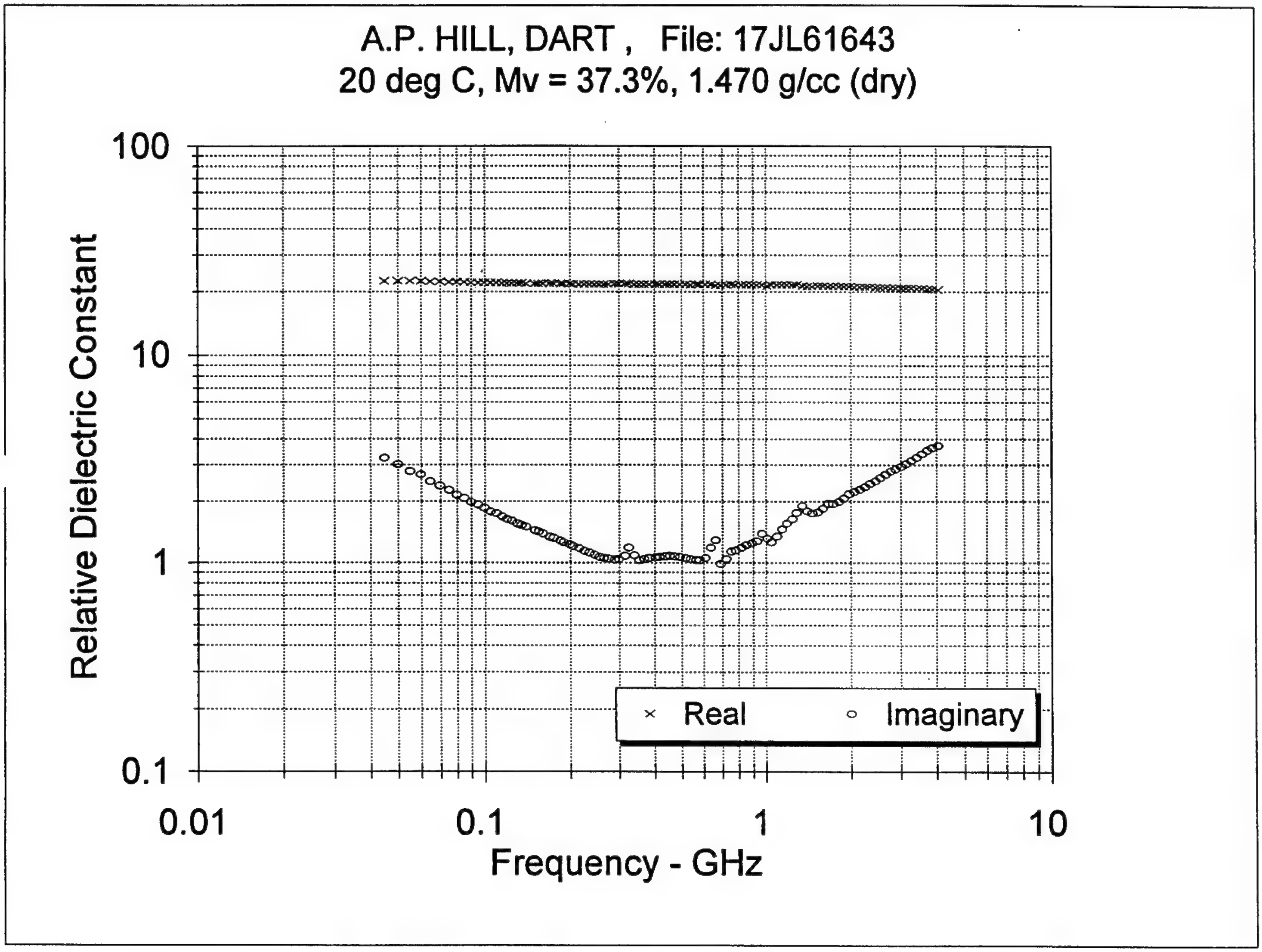
A.P. HILL, DART , File: 16JL61059
20 deg C, Mv = 19.6%, 1.470 g/cc (dry)
Attenuation
Phase Velocity
Attenuation - dB/m
Normalized Phase Velocity
Frequency - GHz
1000
100
10
1
0.01
0.1
1
10
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

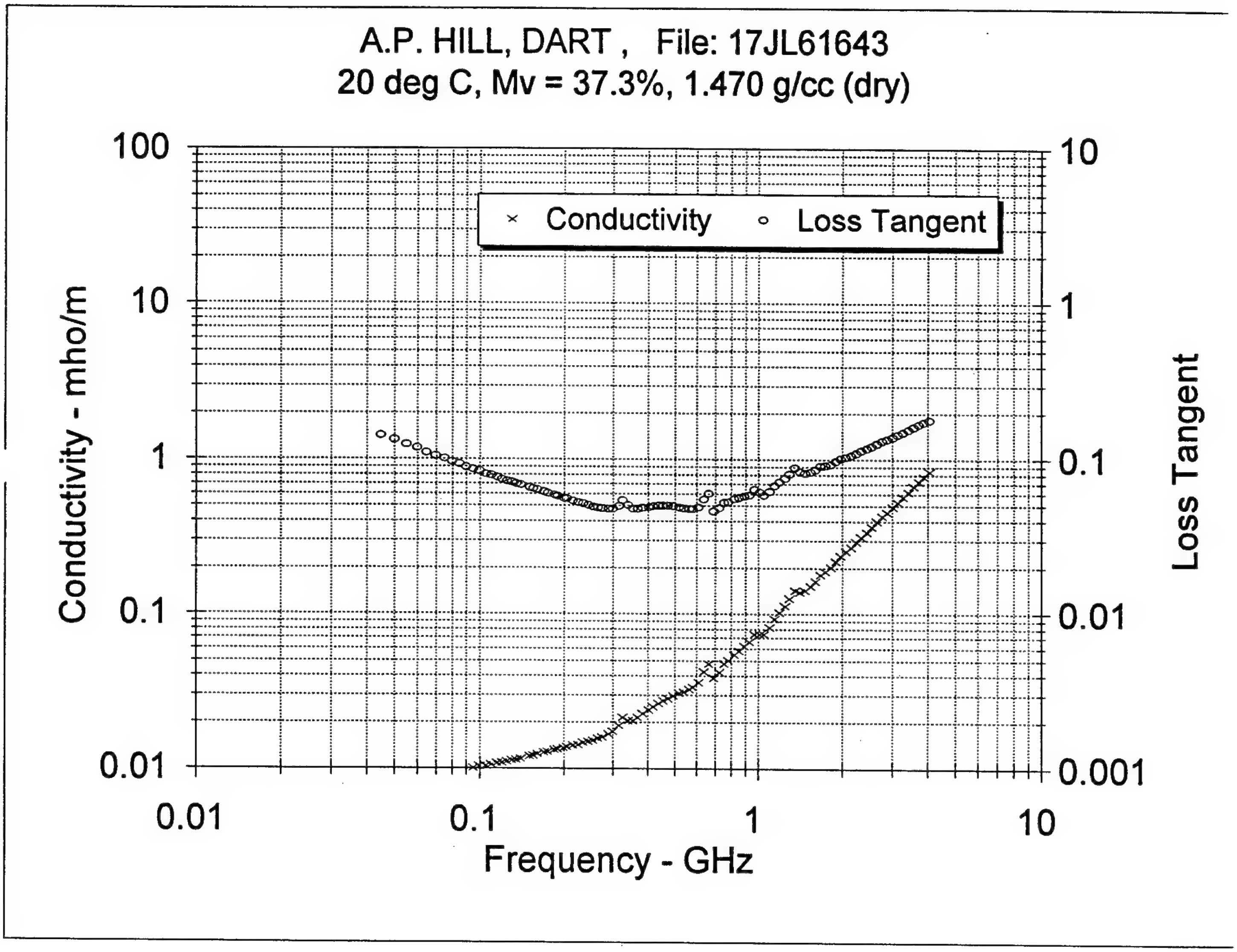
17JL61643
A.P. HILL, DART
9.7
4
37.3
20
1.47

A.P. HILL, DART , File: 17JL61643
20 deg C, Mv = 37.3%, 1.470 g/cc (dry)

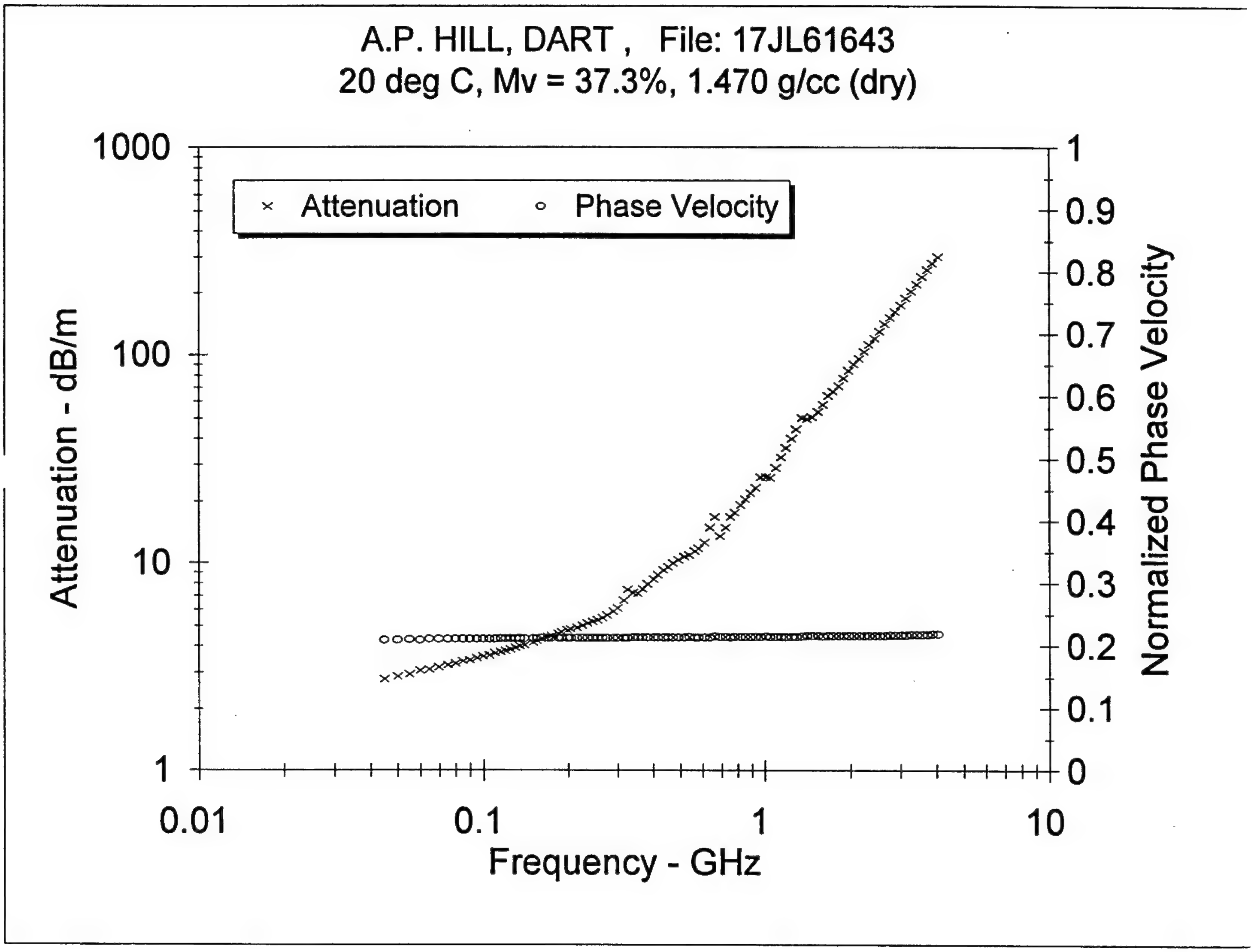
0.045	22.532	3.224	0.0081	0.1431	2.773	0.2101
0.05	22.4839	2.9876	0.0083	0.1329	2.8592	0.2104
0.055	22.4121	2.7851	0.0085	0.1243	2.9374	0.2108
0.06	22.4939	2.6689	0.0089	0.1187	3.0657	0.2105
0.065	22.3357	2.4758	0.0089	0.1108	3.0925	0.2113
0.07	22.3268	2.3577	0.0092	0.1056	3.1726	0.2113
0.075	22.2535	2.2478	0.0094	0.101	3.2465	0.2117
0.08	22.2132	2.136	0.0095	0.0962	3.2941	0.2119
0.085	22.1873	2.0604	0.0097	0.0929	3.3783	0.2121
0.09	22.1611	1.9788	0.0099	0.0893	3.4377	0.2122
0.095	22.1354	1.9128	0.0101	0.0864	3.5098	0.2123
0.1	22.0987	1.8511	0.0103	0.0838	3.5785	0.2125
0.105	22.0659	1.7763	0.0104	0.0805	3.6086	0.2127
0.11	22.0606	1.7399	0.0106	0.0789	3.7036	0.2127
0.115	22.0312	1.6835	0.0108	0.0764	3.749	0.2129
0.12	22.021	1.6316	0.0109	0.0741	3.7925	0.213
0.125	21.9986	1.5975	0.0111	0.0726	3.87	0.2131
0.13	21.9779	1.5588	0.0113	0.0709	3.9293	0.2132
0.135	21.9634	1.5239	0.0114	0.0694	3.9906	0.2132
0.14	21.9442	1.4954	0.0116	0.0681	4.0627	0.2133
0.15	21.9239	1.4375	0.012	0.0656	4.1865	0.2135
0.155	21.9126	1.4145	0.0122	0.0646	4.258	0.2135
0.16	21.9051	1.3898	0.0124	0.0634	4.3194	0.2136
0.17	21.8787	1.34	0.0127	0.0612	4.4277	0.2137
0.175	21.867	1.318	0.0128	0.0603	4.4845	0.2138
0.185	21.8506	1.2786	0.0132	0.0585	4.6009	0.2138
0.19	21.8442	1.2611	0.0133	0.0577	4.6611	0.2139
0.2	21.833	1.2253	0.0136	0.0561	4.7686	0.2139
0.205	21.8256	1.2086	0.0138	0.0554	4.8219	0.214
0.215	21.8158	1.1759	0.0141	0.0539	4.9216	0.214
0.225	21.8174	1.1462	0.0143	0.0525	5.0205	0.214
0.235	21.8139	1.1243	0.0147	0.0515	5.1437	0.214
0.245	21.8135	1.0948	0.0149	0.0502	5.2219	0.214
0.255	21.8231	1.0735	0.0152	0.0492	5.3285	0.214
0.265	21.8189	1.0574	0.0156	0.0485	5.4551	0.214
0.275	21.8291	1.0488	0.016	0.048	5.6134	0.214
0.29	21.8461	1.0396	0.0168	0.0476	5.8656	0.2139
0.3	21.8582	1.0436	0.0174	0.0477	6.0896	0.2138
0.315	21.8855	1.0832	0.019	0.0495	6.6322	0.2137
0.325	21.8617	1.1813	0.0213	0.054	7.4661	0.2138
0.34	21.6815	1.0853	0.0205	0.0501	7.2057	0.2147
0.355	21.7335	1.0313	0.0204	0.0475	7.1409	0.2144
0.37	21.7532	1.0416	0.0214	0.0479	7.514	0.2143
0.385	21.7459	1.0527	0.0225	0.0484	7.9032	0.2144
0.405	21.7294	1.0643	0.024	0.049	8.4086	0.2145
0.42	21.7123	1.0719	0.025	0.0494	8.7852	0.2145
0.44	21.6846	1.0781	0.0264	0.0497	9.2631	0.2147
0.455	21.666	1.0809	0.0273	0.0499	9.6072	0.2148
0.475	21.6438	1.076	0.0284	0.0497	9.9894	0.2149

0.495	21.6247	1.0707	0.0295	0.0495	10.3632	0.215
0.52	21.6127	1.0562	0.0305	0.0489	10.743	0.215
0.54	21.6064	1.0429	0.0313	0.0483	11.0173	0.2151
0.565	21.6147	1.0315	0.0324	0.0477	11.3984	0.215
0.585	21.6322	1.0299	0.0335	0.0476	11.7791	0.2149
0.61	21.6653	1.0554	0.0358	0.0487	12.5772	0.2148
0.64	21.6884	1.1904	0.0424	0.0549	14.8749	0.2146
0.665	21.418	1.2911	0.0477	0.0603	16.8666	0.216
0.695	21.4741	0.9924	0.0384	0.0462	13.5345	0.2157
0.725	21.5804	1.0448	0.0421	0.0484	14.8275	0.2152
0.755	21.6162	1.132	0.0475	0.0524	16.7142	0.215
0.785	21.6024	1.1496	0.0502	0.0532	17.6549	0.2151
0.82	21.5833	1.1908	0.0543	0.0552	19.1112	0.2152
0.855	21.5618	1.2192	0.058	0.0565	20.4108	0.2153
0.895	21.5491	1.242	0.0618	0.0576	21.7725	0.2153
0.93	21.5588	1.2724	0.0658	0.059	23.1715	0.2153
0.97	21.5482	1.3783	0.0743	0.064	26.1846	0.2153
1.015	21.3692	1.308	0.0738	0.0612	26.1098	0.2162
1.055	21.5139	1.2582	0.0738	0.0585	26.0202	0.2155
1.1	21.5814	1.3476	0.0824	0.0624	29.0099	0.2152
1.15	21.5952	1.4577	0.0932	0.0675	32.7928	0.2151
1.195	21.5777	1.5467	0.1028	0.0717	36.1694	0.2151
1.25	21.5488	1.6345	0.1136	0.0759	40.0052	0.2153
1.3	21.5426	1.7495	0.1265	0.0812	44.5342	0.2153
1.36	21.3187	1.8826	0.1424	0.0883	50.3896	0.2164
1.415	21.2192	1.7774	0.1399	0.0838	49.619	0.2169
1.475	21.2465	1.74	0.1427	0.0819	50.6021	0.2168
1.54	21.2779	1.7663	0.1513	0.083	53.5909	0.2166
1.605	21.2935	1.8378	0.164	0.0863	58.0882	0.2165
1.675	21.2423	1.9319	0.1799	0.0909	63.7977	0.2167
1.745	21.2019	1.9406	0.1883	0.0915	66.8251	0.2169
1.82	21.2099	1.9841	0.2008	0.0935	71.2406	0.2169
1.9	21.2086	2.0635	0.218	0.0973	77.3446	0.2169
1.98	21.1806	2.154	0.2372	0.1017	84.182	0.217
2.065	21.1211	2.2149	0.2543	0.1049	90.399	0.2173
2.155	21.1035	2.2602	0.2708	0.1071	96.3039	0.2174
2.25	21.0888	2.3329	0.2919	0.1106	103.8072	0.2174
2.345	21.0632	2.4188	0.3154	0.1148	112.229	0.2175
2.445	21.0291	2.4933	0.339	0.1186	120.7036	0.2177
2.55	21.0066	2.5825	0.3662	0.1229	130.4445	0.2178
2.66	20.9641	2.6849	0.3971	0.1281	141.5903	0.218
2.775	20.9059	2.769	0.4273	0.1324	152.5259	0.2182
2.89	20.8693	2.8389	0.4562	0.136	162.9829	0.2184
3.015	20.8393	2.9258	0.4905	0.1404	175.3351	0.2185
3.145	20.8055	3.0255	0.5291	0.1454	189.2503	0.2187
3.28	20.768	3.1341	0.5716	0.1509	204.5985	0.2188
3.42	20.7244	3.2493	0.6179	0.1568	221.3608	0.219
3.57	20.6693	3.3746	0.6699	0.1633	240.2341	0.2192
3.72	20.6029	3.4916	0.7223	0.1695	259.3598	0.2195
3.88	20.5363	3.602	0.7771	0.1754	279.4477	0.2198
4.045	20.4813	3.7143	0.8354	0.1814	300.7429	0.2201


A.P. HILL, DART , File: 17JL61643
20 deg C, Mv = 37.3%, 1.470 g/cc (dry)
100
10
1
0.1
Relative Dielectric Constant
0.01
0.1
1
10
Frequency - GHz
Real
Imaginary



A.P. HILL, DART , File: 17JL61643
20 deg C, Mv = 37.3%, 1.470 g/cc (dry)
Conductivity
Loss Tangent
100
10
1
0.1
0.01
Conductivity - mho/m
10
1
0.1
0.01
0.001
Loss Tangent
0.01
0.1
1
10
Frequency - GHz

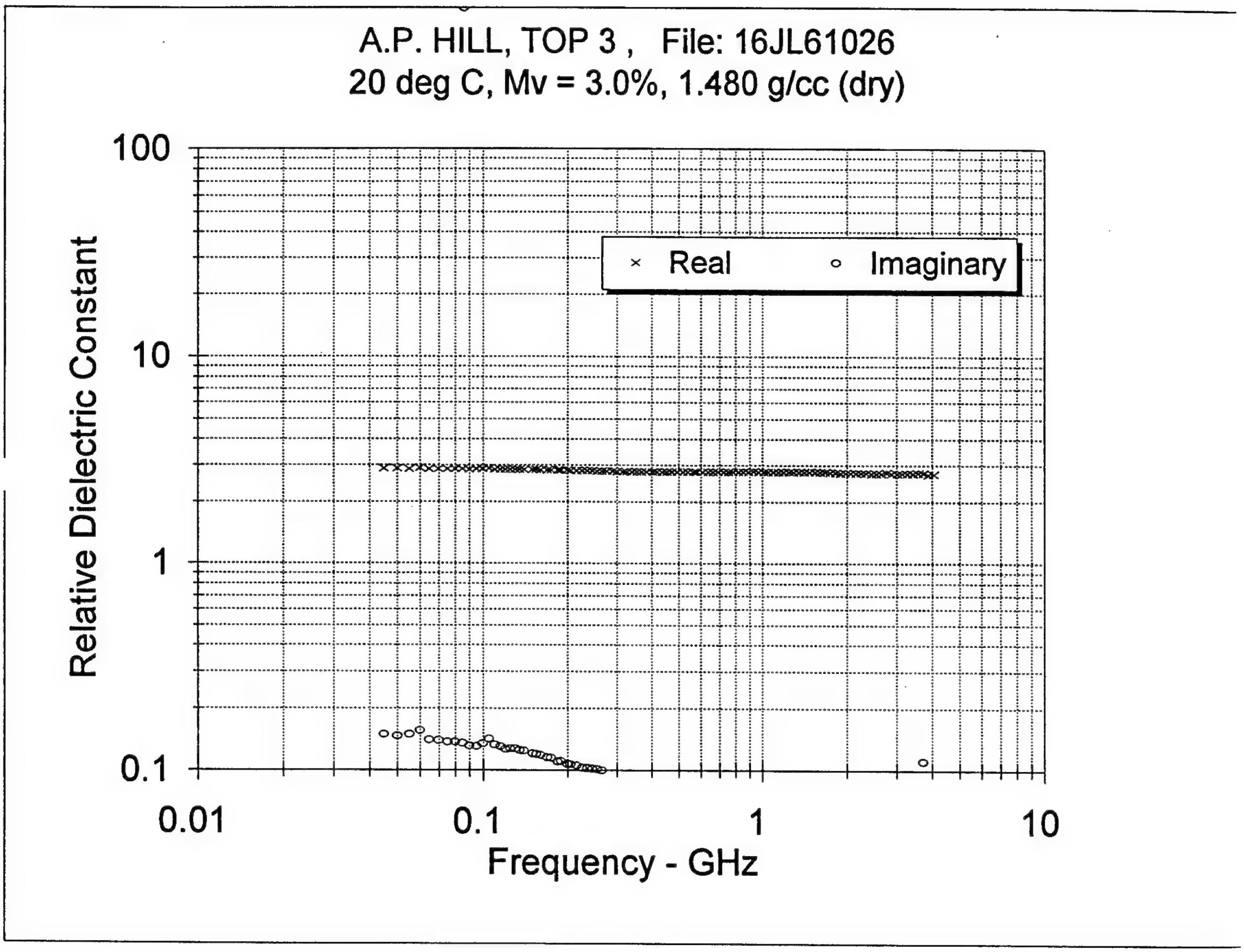


A.P. HILL, DART , File: 17JL61643
20 deg C, Mv = 37.3%, 1.470 g/cc (dry)
Attenuation
Phase Velocity
Attenuation - dB/m
Normalized Phase Velocity
Frequency - GHz
1000
100
10
1
0.01
0.1
1
10
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0

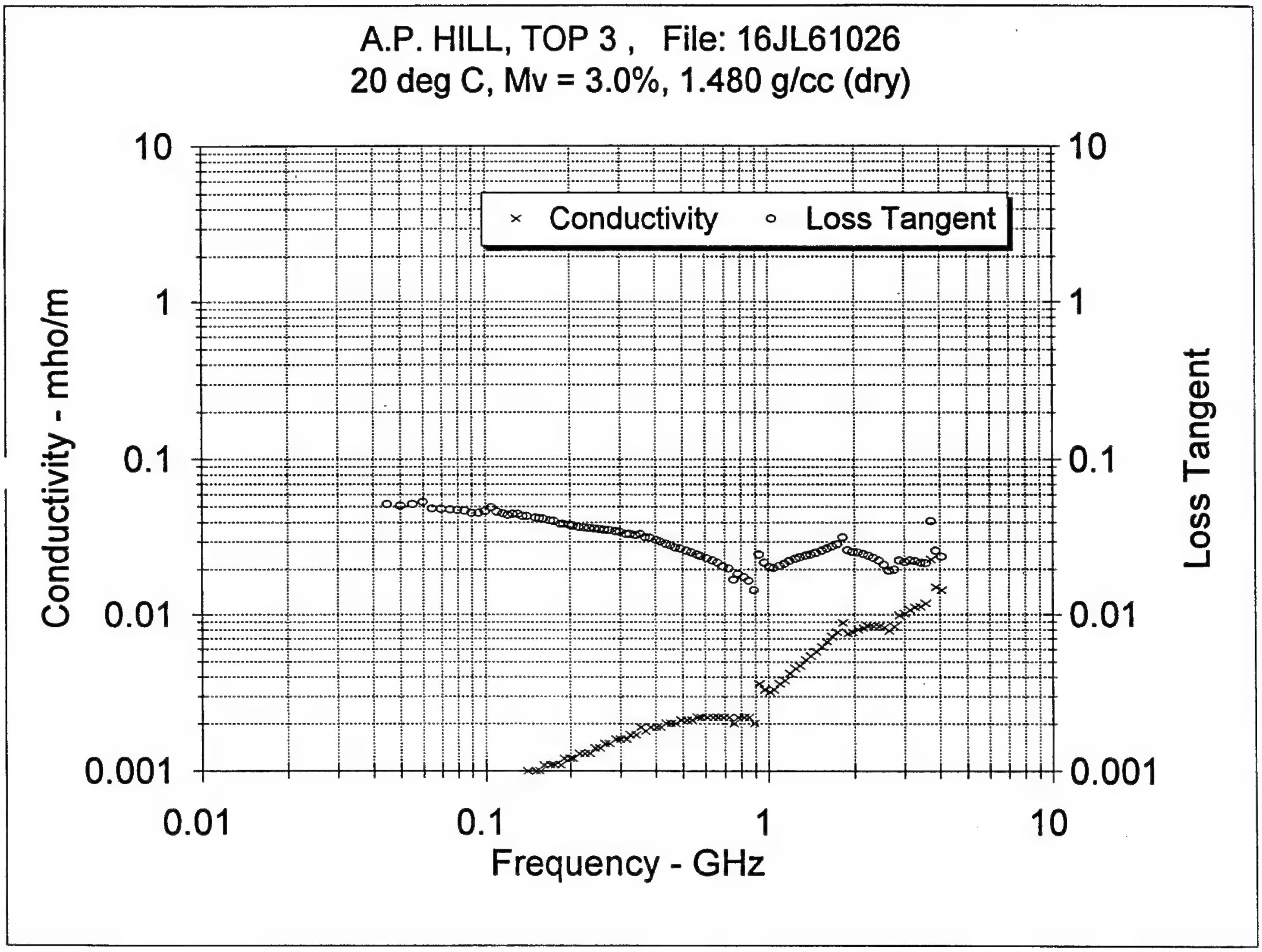
16JL61026
A.P. HILL, TOP 3

9.7						
2		A.P. HILL, TOP 3 , File: 16JL61026				
3		20 deg C, Mv = 3.0%, 1.480 g/cc (dry)				
20						
1.48						
0.045	2.8709	0.1486	0.0004	0.0518	0.3588	0.59
0.05	2.8674	0.1457	0.0004	0.0508	0.3912	0.5904
0.055	2.8623	0.1486	0.0005	0.0519	0.4394	0.5909
0.06	2.8877	0.155	0.0005	0.0537	0.4977	0.5883
0.065	2.8613	0.1399	0.0005	0.0489	0.4887	0.591
0.07	2.8621	0.1389	0.0005	0.0485	0.5227	0.5909
0.075	2.8573	0.1371	0.0006	0.048	0.5533	0.5914
0.08	2.856	0.1366	0.0006	0.0478	0.5879	0.5916
0.085	2.8557	0.1347	0.0006	0.0472	0.6161	0.5916
0.09	2.8491	0.1312	0.0007	0.046	0.636	0.5923
0.095	2.8539	0.131	0.0007	0.0459	0.6699	0.5918
0.1	2.856	0.1338	0.0007	0.0469	0.7202	0.5916
0.105	2.8684	0.1421	0.0008	0.0496	0.8013	0.5903
0.11	2.8495	0.1324	0.0008	0.0465	0.7847	0.5922
0.115	2.8478	0.1298	0.0008	0.0456	0.8044	0.5924
0.12	2.8475	0.1264	0.0008	0.0444	0.8172	0.5925
0.125	2.8457	0.1274	0.0009	0.0448	0.8588	0.5926
0.13	2.8416	0.1276	0.0009	0.0449	0.8946	0.5931
0.135	2.8423	0.1244	0.0009	0.0438	0.9058	0.593
0.14	2.8416	0.1238	0.001	0.0436	0.9353	0.5931
0.15	2.8385	0.1202	0.001	0.0424	0.9735	0.5934
0.155	2.836	0.1196	0.001	0.0422	1.0012	0.5937
0.16	2.8343	0.1186	0.0011	0.0418	1.0248	0.5939
0.17	2.8312	0.1154	0.0011	0.0408	1.0607	0.5942
0.175	2.8291	0.1146	0.0011	0.0405	1.0843	0.5944
0.185	2.8264	0.1102	0.0011	0.039	1.103	0.5947
0.19	2.8255	0.1104	0.0012	0.0391	1.1343	0.5948
0.2	2.8219	0.1081	0.0012	0.0383	1.1705	0.5952
0.205	2.8203	0.107	0.0012	0.0379	1.1874	0.5953
0.215	2.8177	0.1055	0.0013	0.0374	1.2288	0.5956
0.225	2.8147	0.1035	0.0013	0.0368	1.2627	0.596
0.235	2.8098	0.1024	0.0013	0.0365	1.306	0.5965
0.245	2.8087	0.1019	0.0014	0.0363	1.355	0.5966
0.255	2.8032	0.1011	0.0014	0.036	1.3997	0.5972
0.265	2.8001	0.1003	0.0015	0.0358	1.4451	0.5975
0.275	2.7965	0.0994	0.0015	0.0356	1.4869	0.5979
0.29	2.7925	0.0979	0.0016	0.035	1.5445	0.5983
0.3	2.7901	0.0963	0.0016	0.0345	1.5723	0.5986
0.315	2.783	0.0933	0.0016	0.0335	1.6024	0.5994
0.325	2.7855	0.0933	0.0017	0.0335	1.6522	0.5991
0.34	2.785	0.0917	0.0017	0.0329	1.6997	0.5991
0.355	2.7862	0.0938	0.0019	0.0337	1.8138	0.599
0.37	2.7806	0.0891	0.0018	0.032	1.7974	0.5996
0.385	2.7803	0.0884	0.0019	0.0318	1.8556	0.5997
0.405	2.7785	0.085	0.0019	0.0306	1.8787	0.5999
0.42	2.7775	0.0834	0.0019	0.03	1.9121	0.6
0.44	2.7753	0.0806	0.002	0.029	1.9362	0.6002
0.455	2.7742	0.0785	0.002	0.0283	1.9509	0.6003
0.475	2.7723	0.0762	0.002	0.0275	1.9772	0.6005

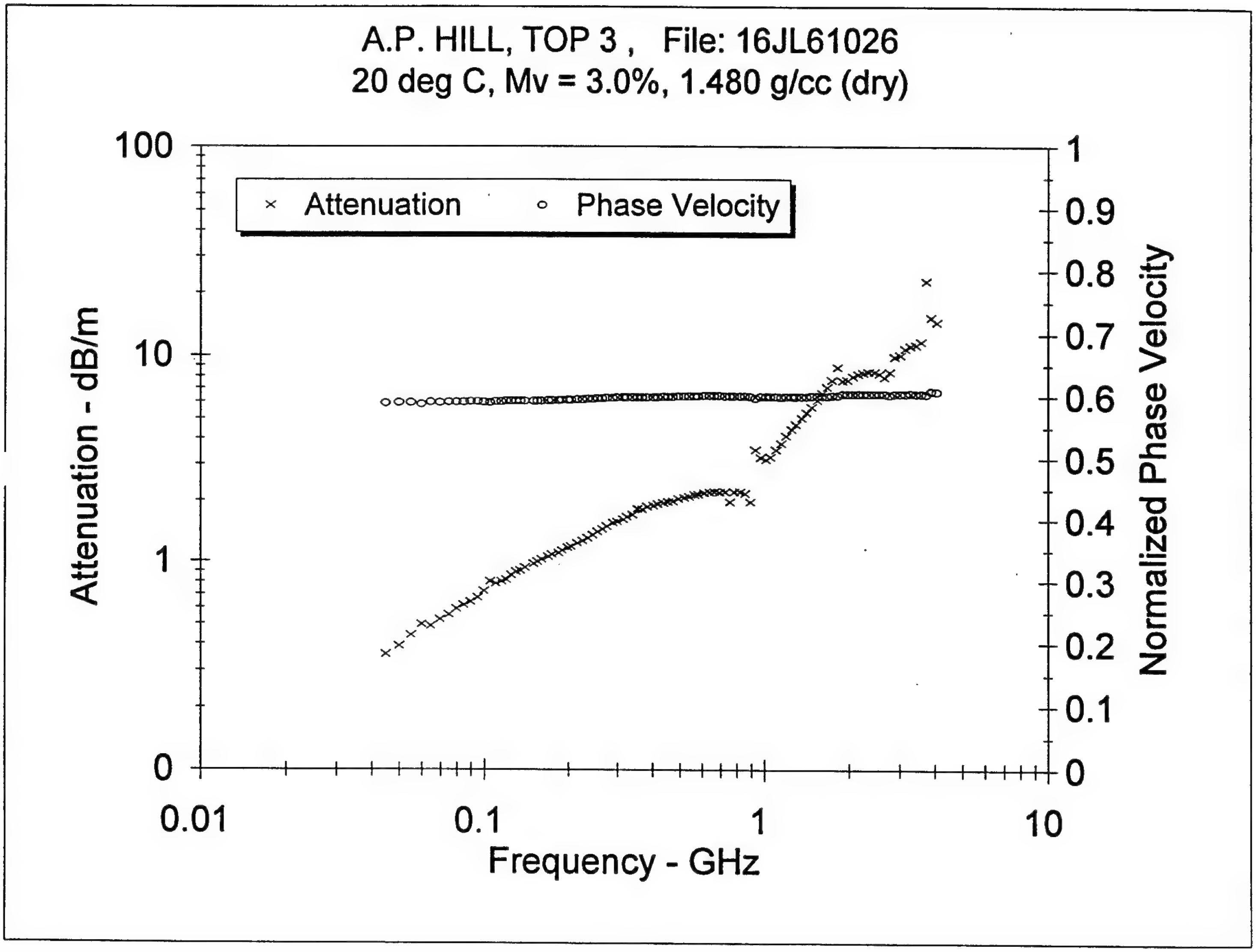
0.495	2.7703	0.0749	0.0021	0.027	2.0259	0.6008
0.52	2.7681	0.0723	0.0021	0.0261	2.0559	0.601
0.54	2.7666	0.0706	0.0021	0.0255	2.0855	0.6012
0.565	2.7643	0.0684	0.0022	0.0248	2.1156	0.6014
0.585	2.7636	0.0666	0.0022	0.0241	2.1318	0.6015
0.61	2.7629	0.065	0.0022	0.0235	2.1702	0.6016
0.64	2.7631	0.0624	0.0022	0.0226	2.1857	0.6016
0.665	2.763	0.0602	0.0022	0.0218	2.1906	0.6016
0.695	2.763	0.0573	0.0022	0.0207	2.179	0.6016
0.725	2.7637	0.0556	0.0022	0.0201	2.2035	0.6015
0.755	2.7684	0.0474	0.002	0.0171	1.9569	0.601
0.785	2.7638	0.0511	0.0022	0.0185	2.1936	0.6015
0.82	2.7646	0.049	0.0022	0.0177	2.1986	0.6014
0.855	2.7664	0.0463	0.0022	0.0167	2.1641	0.6012
0.895	2.7716	0.0402	0.002	0.0145	1.9651	0.6007
0.93	2.8034	0.0692	0.0036	0.0247	3.4936	0.5972
0.97	2.7726	0.0607	0.0033	0.0219	3.216	0.6005
1.015	2.7729	0.0568	0.0032	0.0205	3.1509	0.6005
1.055	2.7747	0.0563	0.0033	0.0203	3.2416	0.6003
1.1	2.7768	0.0582	0.0036	0.021	3.4953	0.6001
1.15	2.7771	0.0601	0.0038	0.0216	3.7717	0.6
1.195	2.7765	0.0626	0.0042	0.0225	4.08	0.6001
1.25	2.7743	0.0643	0.0045	0.0232	4.3891	0.6003
1.3	2.773	0.0656	0.0047	0.0237	4.6612	0.6005
1.36	2.7725	0.0673	0.0051	0.0243	4.9972	0.6005
1.415	2.7719	0.0687	0.0054	0.0248	5.3127	0.6006
1.475	2.7701	0.0701	0.0058	0.0253	5.6523	0.6008
1.54	2.7681	0.0726	0.0062	0.0262	6.1081	0.601
1.605	2.7665	0.075	0.0067	0.0271	6.5848	0.6012
1.675	2.7636	0.0771	0.0072	0.0279	7.0654	0.6015
1.745	2.7607	0.0798	0.0077	0.0289	7.6182	0.6018
1.82	2.7571	0.0881	0.0089	0.0319	8.7775	0.6022
1.9	2.7349	0.0722	0.0076	0.0264	7.5395	0.6046
1.98	2.7418	0.0702	0.0077	0.0256	7.6365	0.6039
2.065	2.7415	0.0699	0.008	0.0255	7.9234	0.6039
2.155	2.7393	0.0685	0.0082	0.025	8.1086	0.6042
2.25	2.7376	0.0668	0.0084	0.0244	8.263	0.6043
2.345	2.7352	0.0646	0.0084	0.0236	8.3246	0.6046
2.445	2.7334	0.0619	0.0084	0.0226	8.3196	0.6048
2.55	2.7321	0.0582	0.0083	0.0213	8.1666	0.605
2.66	2.7341	0.0534	0.0079	0.0195	7.8127	0.6047
2.775	2.7503	0.0546	0.0084	0.0199	8.3132	0.603
2.89	2.7316	0.0618	0.0099	0.0226	9.8289	0.605
3.015	2.7333	0.0606	0.0102	0.0222	10.0504	0.6048
3.145	2.7313	0.062	0.0108	0.0227	10.7375	0.605
3.28	2.7288	0.0613	0.0112	0.0225	11.0762	0.6053
3.42	2.7295	0.0595	0.0113	0.0218	11.1968	0.6052
3.57	2.7392	0.0595	0.0118	0.0217	11.6692	0.6042
3.72	2.7444	0.1109	0.0229	0.0404	22.6461	0.6035
3.88	2.6958	0.0706	0.0152	0.0262	15.1806	0.609
4.045	2.7066	0.0646	0.0145	0.0239	14.4552	0.6078



A.P. HILL, TOP 3 , File: 16JL61026
20 deg C, Mv = 3.0%, 1.480 g/cc (dry)
Real
Imaginary
Relative Dielectric Constant
100
10
1
0.1
0.01
0.1
1
10
Frequency - GHz



A.P. HILL, TOP 3 ,   File: 16JL61026
20 deg C, Mv = 3.0%, 1.480 g/cc (dry)
Conductivity
Loss Tangent
Conductivity - mho/m
Loss Tangent
Frequency - GHz
10
1
0.1
0.01
0.001
0.01
0.1
1
10

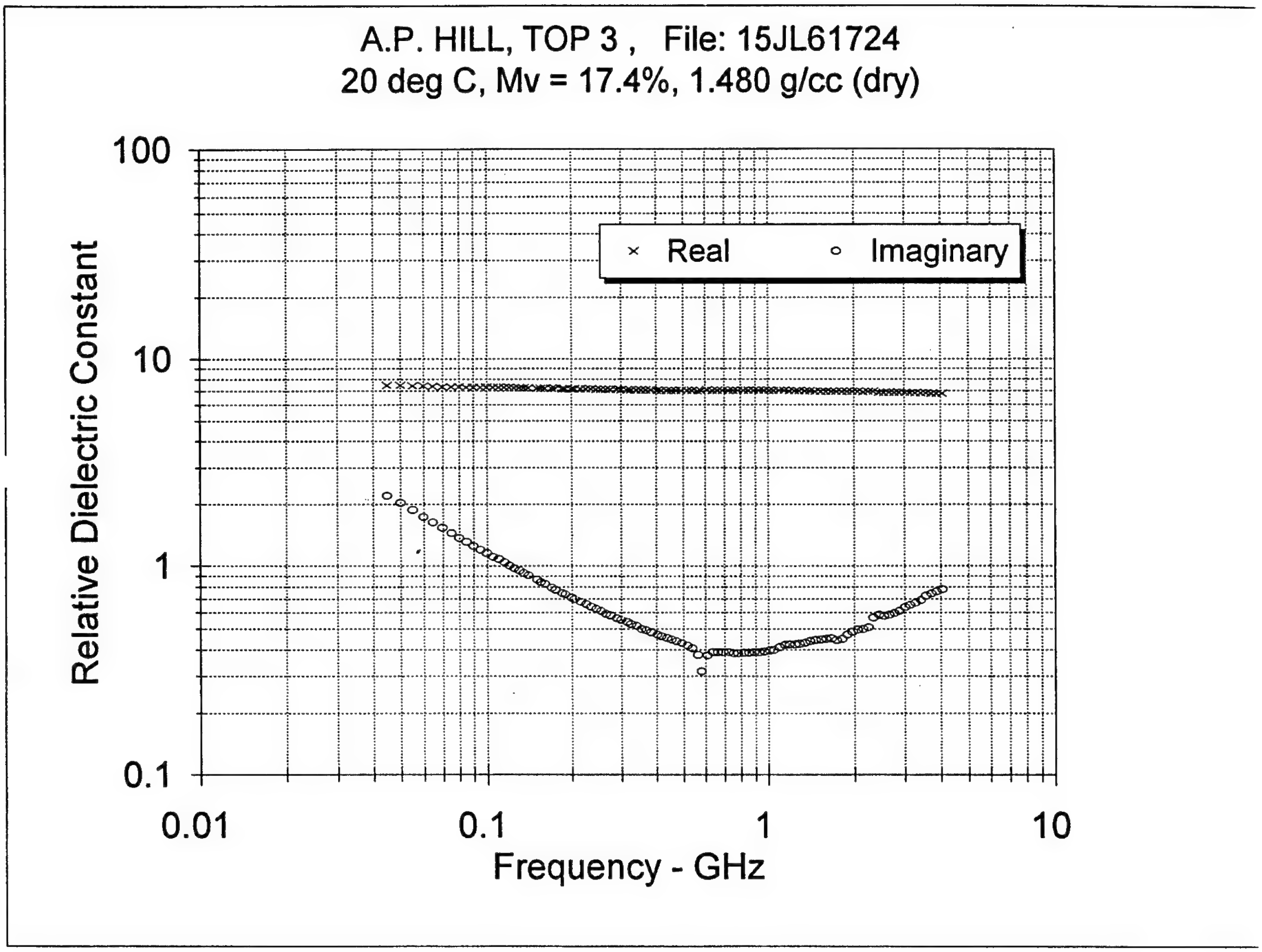

A.P. HILL, TOP 3 , File: 16JL61026
20 deg C, Mv = 3.0%, 1.480 g/cc (dry)
Attenuation
Phase Velocity
100
10
1
0
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.01
0.1
1
10
Frequency - GHz
Attenuation - dB/m
Normalized Phase Velocity

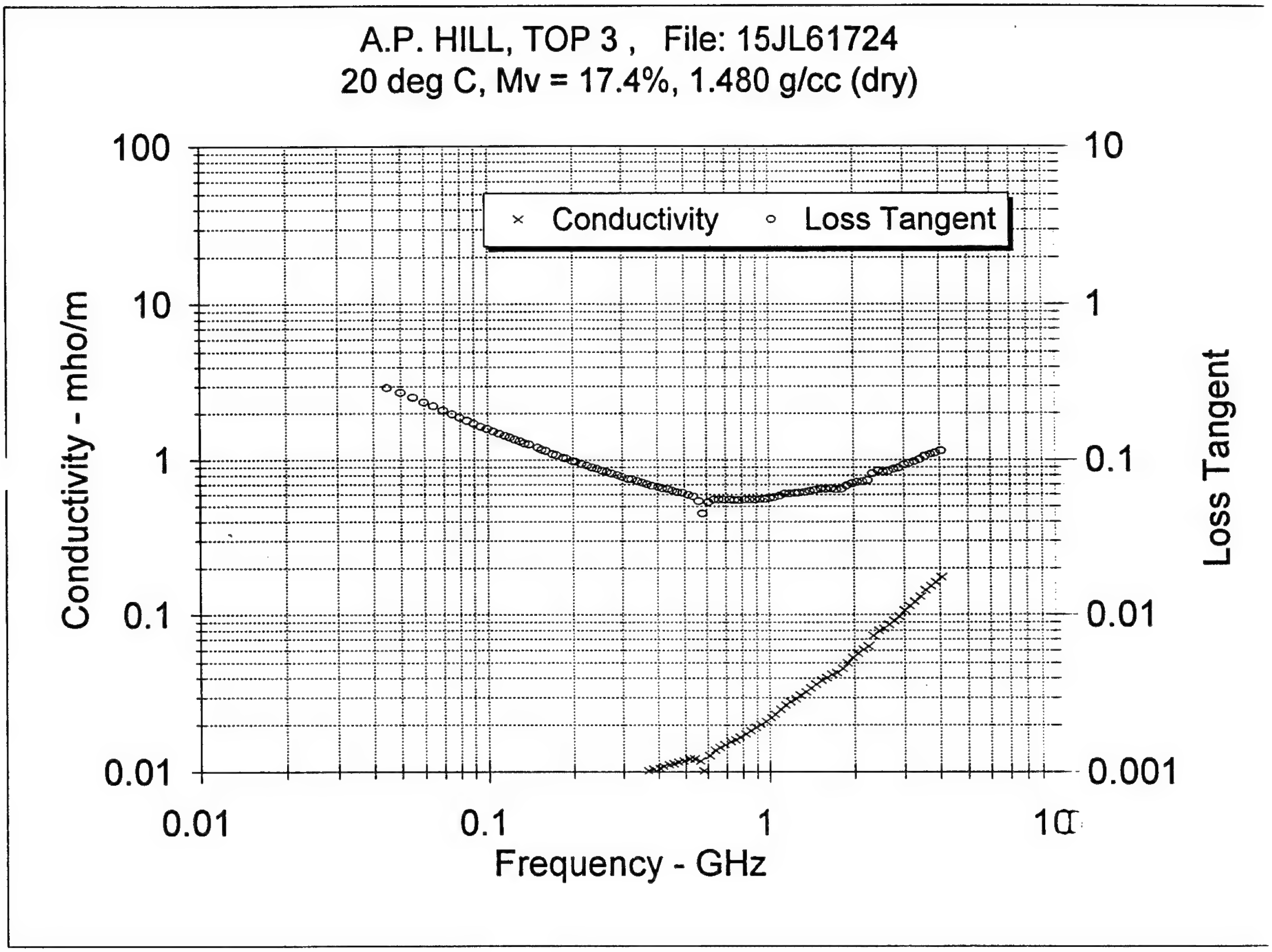
15JL61724
A.P. HILL, TOP 3

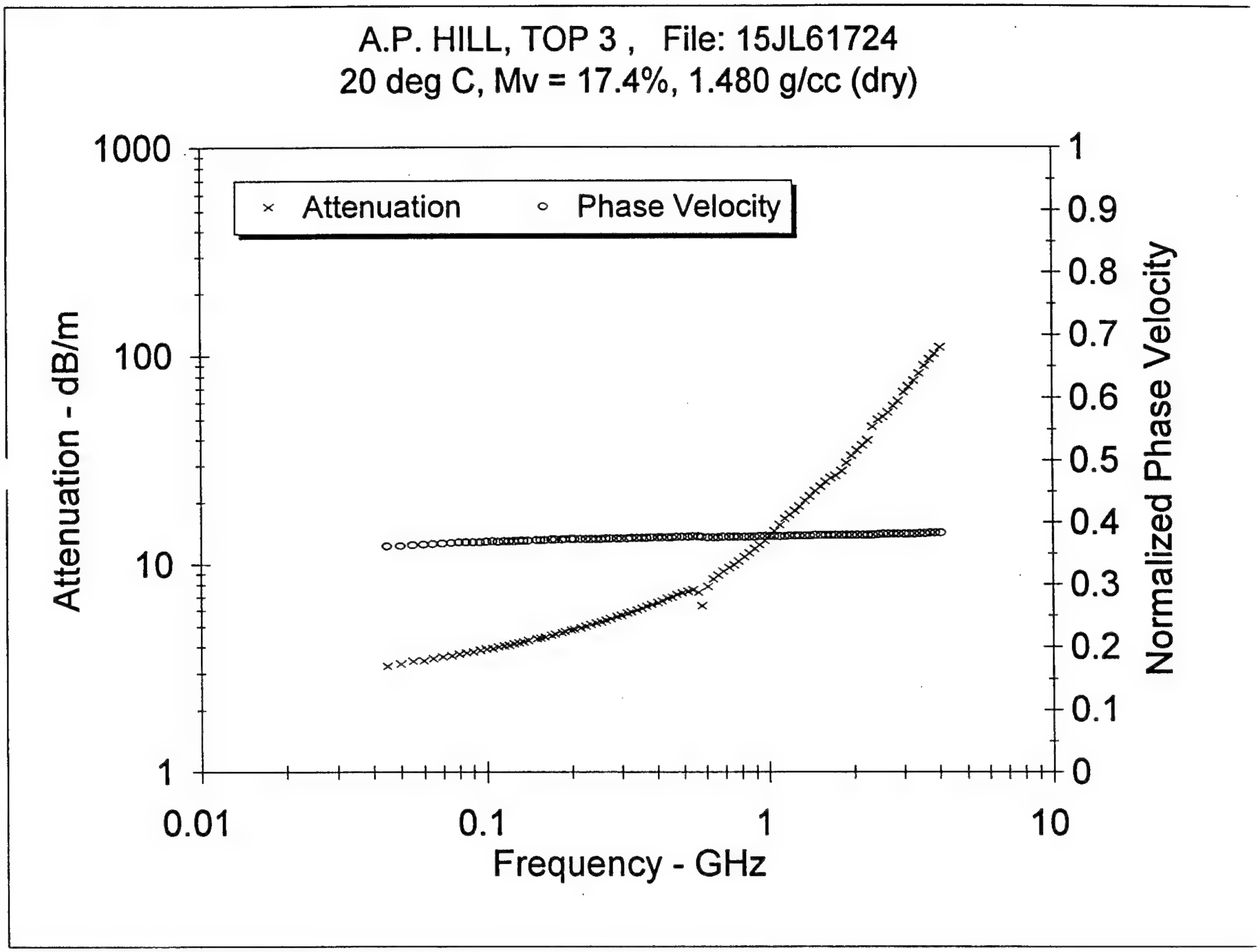
9.7
2 A.P. HILL, TOP 3 , File: 15JL61724
17.4 20 deg C, Mv = 17.4%, 1.480 g/cc (dry)
20
1.48

0.045	7.4504	2.1877	0.0055	0.2936	3.2465	0.3626
0.05	7.4187	2.0132	0.0056	0.2714	3.3316	0.3639
0.055	7.3845	1.869	0.0057	0.2531	3.414	0.3651
0.06	7.3756	1.731	0.0058	0.2347	3.4551	0.3657
0.065	7.3477	1.6295	0.0059	0.2218	3.5328	0.3667
0.07	7.3339	1.5362	0.006	0.2095	3.5922	0.3673
0.075	7.3138	1.4502	0.006	0.1983	3.6406	0.368
0.08	7.2979	1.377	0.0061	0.1887	3.693	0.3685
0.085	7.2893	1.3129	0.0062	0.1801	3.7446	0.3689
0.09	7.2757	1.2538	0.0063	0.1723	3.7914	0.3694
0.095	7.268	1.2022	0.0064	0.1654	3.8403	0.3697
0.1	7.2575	1.1596	0.0064	0.1598	3.9028	0.37
0.105	7.2369	1.1078	0.0065	0.1531	3.9214	0.3707
0.11	7.2395	1.0796	0.0066	0.1491	4.0034	0.3706
0.115	7.2303	1.0429	0.0067	0.1442	4.0465	0.3709
0.12	7.2264	1.0082	0.0067	0.1395	4.0838	0.3711
0.125	7.2146	0.9804	0.0068	0.1359	4.1406	0.3714
0.13	7.2078	0.9534	0.0069	0.1323	4.19	0.3717
0.135	7.1999	0.9257	0.0069	0.1286	4.2275	0.3719
0.14	7.1964	0.9045	0.007	0.1257	4.2851	0.372
0.15	7.1844	0.8603	0.0072	0.1198	4.3716	0.3724
0.155	7.1776	0.8396	0.0072	0.117	4.4106	0.3726
0.16	7.1709	0.8216	0.0073	0.1146	4.4581	0.3728
0.17	7.1605	0.7879	0.0074	0.11	4.5458	0.3731
0.175	7.1547	0.7717	0.0075	0.1079	4.5859	0.3733
0.185	7.1451	0.7425	0.0076	0.1039	4.6677	0.3736
0.19	7.1415	0.7327	0.0077	0.1026	4.7322	0.3737
0.2	7.1347	0.7058	0.0078	0.0989	4.8009	0.3739
0.205	7.1305	0.696	0.0079	0.0976	4.8547	0.374
0.215	7.1243	0.6747	0.0081	0.0947	4.9379	0.3742
0.225	7.1161	0.6562	0.0082	0.0922	5.0289	0.3745
0.235	7.1111	0.64	0.0084	0.09	5.1245	0.3746
0.245	7.1038	0.6227	0.0085	0.0877	5.2013	0.3748
0.255	7.0961	0.6068	0.0086	0.0855	5.2783	0.3751
0.265	7.0906	0.5936	0.0087	0.0837	5.3683	0.3752
0.275	7.0848	0.5813	0.0089	0.0821	5.4586	0.3754
0.29	7.0754	0.5636	0.0091	0.0797	5.5848	0.3756
0.3	7.0722	0.5536	0.0092	0.0783	5.6758	0.3757
0.315	7.065	0.5386	0.0094	0.0762	5.8017	0.3759
0.325	7.0594	0.528	0.0095	0.0748	5.8705	0.3761
0.34	7.0532	0.5168	0.0098	0.0733	6.0135	0.3763
0.355	7.0446	0.5028	0.0099	0.0714	6.1133	0.3765
0.37	7.0425	0.4936	0.0102	0.0701	6.2562	0.3766
0.385	7.037	0.4841	0.0104	0.0688	6.3863	0.3767
0.405	7.031	0.4716	0.0106	0.0671	6.5476	0.3769
0.42	7.0267	0.4639	0.0108	0.066	6.6823	0.377
0.44	7.0198	0.454	0.0111	0.0647	6.855	0.3772
0.455	7.015	0.446	0.0113	0.0636	6.9661	0.3774
0.475	7.0094	0.4373	0.0115	0.0624	7.1326	0.3775

0.495	7.0022	0.4286	0.0118	0.0612	7.2888	0.3777
0.52	6.9925	0.4172	0.0121	0.0597	7.4585	0.378
0.54	6.9819	0.4064	0.0122	0.0582	7.5511	0.3783
0.565	6.9634	0.3767	0.0118	0.0541	7.3327	0.3788
0.585	7.0064	0.314	0.0102	0.0448	6.3115	0.3777
0.61	7.039	0.3756	0.0127	0.0534	7.8517	0.3768
0.64	7.023	0.3887	0.0138	0.0553	8.5343	0.3772
0.665	7.015	0.3892	0.0144	0.0555	8.8848	0.3774
0.695	7.0088	0.3884	0.015	0.0554	9.2711	0.3776
0.725	7.0059	0.3881	0.0156	0.0554	9.6655	0.3777
0.755	6.9991	0.3843	0.0161	0.0549	9.9729	0.3778
0.785	6.9974	0.3856	0.0168	0.0551	10.4046	0.3779
0.82	6.9942	0.3861	0.0176	0.0552	10.8854	0.378
0.855	6.9916	0.3861	0.0184	0.0552	11.3516	0.378
0.895	6.988	0.388	0.0193	0.0555	11.9438	0.3781
0.93	6.9853	0.3896	0.0201	0.0558	12.4652	0.3782
0.97	6.982	0.3916	0.0211	0.0561	13.0702	0.3783
1.015	6.9795	0.3954	0.0223	0.0567	13.8118	0.3784
1.055	6.9787	0.3997	0.0234	0.0573	14.5125	0.3784
1.1	6.9789	0.4094	0.025	0.0587	15.4992	0.3784
1.15	6.9681	0.4213	0.0269	0.0605	16.6882	0.3787
1.195	6.9538	0.4223	0.0281	0.0607	17.4005	0.379
1.25	6.9469	0.4228	0.0294	0.0609	18.2318	0.3792
1.3	6.943	0.4254	0.0308	0.0613	19.082	0.3793
1.36	6.9381	0.4317	0.0326	0.0622	20.2629	0.3795
1.415	6.9321	0.4376	0.0344	0.0631	21.3829	0.3796
1.475	6.9239	0.4436	0.0364	0.0641	22.607	0.3798
1.54	6.9151	0.448	0.0384	0.0648	23.8502	0.3801
1.605	6.9071	0.4509	0.0402	0.0653	25.0326	0.3803
1.675	6.8982	0.4524	0.0421	0.0656	26.2295	0.3805
1.745	6.8927	0.4437	0.0431	0.0644	26.8104	0.3807
1.82	6.912	0.4504	0.0456	0.0652	28.3468	0.3802
1.9	6.9109	0.4711	0.0498	0.0682	30.9504	0.3802
1.98	6.9034	0.4863	0.0535	0.0704	33.3155	0.3804
2.065	6.894	0.4977	0.0571	0.0722	35.5802	0.3806
2.155	6.8879	0.5027	0.0602	0.073	37.5223	0.3808
2.25	6.9001	0.5099	0.0638	0.0739	39.7031	0.3804
2.345	6.9108	0.5672	0.074	0.0821	45.9797	0.3801
2.445	6.8526	0.5866	0.0797	0.0856	49.7878	0.3817
2.55	6.8396	0.5763	0.0817	0.0843	51.0664	0.382
2.66	6.8386	0.583	0.0862	0.0852	53.8886	0.3821
2.775	6.8346	0.5961	0.092	0.0872	57.502	0.3821
2.89	6.8355	0.6088	0.0978	0.0891	61.1509	0.3821
3.015	6.8272	0.6376	0.1069	0.0934	66.8466	0.3823
3.145	6.8137	0.6514	0.1139	0.0956	71.3087	0.3827
3.28	6.8102	0.6669	0.1216	0.0979	76.1539	0.3827
3.42	6.8079	0.6895	0.1311	0.1013	82.1015	0.3828
3.57	6.7972	0.7214	0.1432	0.1061	89.7252	0.383
3.72	6.7768	0.7396	0.153	0.1091	95.9861	0.3836
3.88	6.7662	0.7545	0.1628	0.1115	102.2131	0.3838
4.045	6.7582	0.7762	0.1746	0.1149	109.6815	0.384


A.P. HILL, TOP 3 , File: 15JL61724
20 deg C, Mv = 17.4%, 1.480 g/cc (dry)
100
10
1
0.1
Relative Dielectric Constant
Real
Imaginary
0.01
0.1
1
10
Frequency - GHz


A.P. HILL, TOP 3 , File: 15JL61724
20 deg C, Mv = 17.4%, 1.480 g/cc (dry)
Conductivity
Loss Tangent
Conductivity - mho/m
Loss Tangent
Frequency - GHz
100
10
1
0.1
0.01
10
1
0.1
0.01
0.001
0.01
0.1
1
10

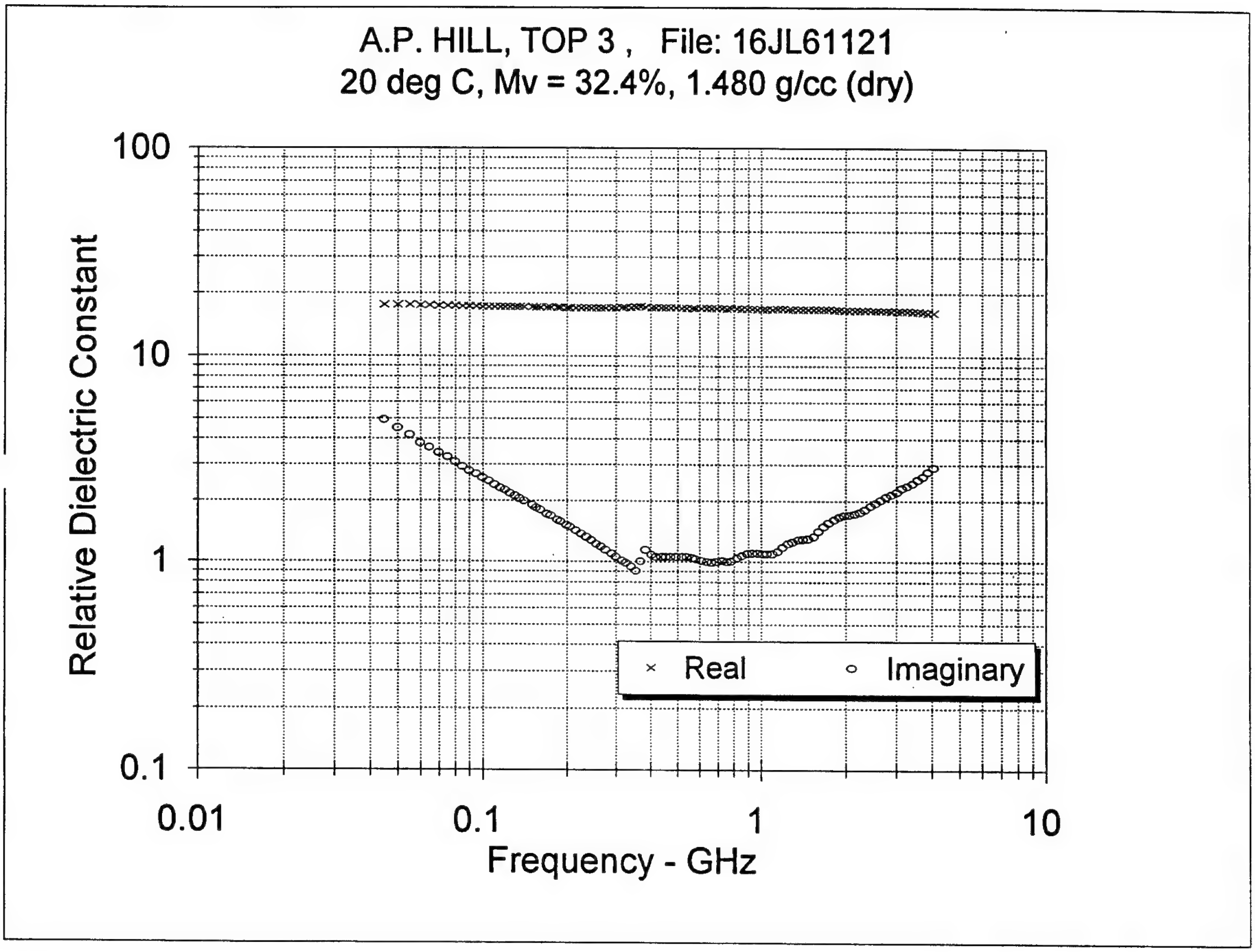

A.P. HILL, TOP 3 , File: 15JL61724
20 deg C, Mv = 17.4%, 1.480 g/cc (dry)
Attenuation
Phase Velocity
Attenuation - dB/m
Normalized Phase Velocity
Frequency - GHz
1000
100
10
1
0.01
0.1
1
10
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

16JL61121
A.P. HILL, TOP 3
9.7
2
32.4
20
1.48

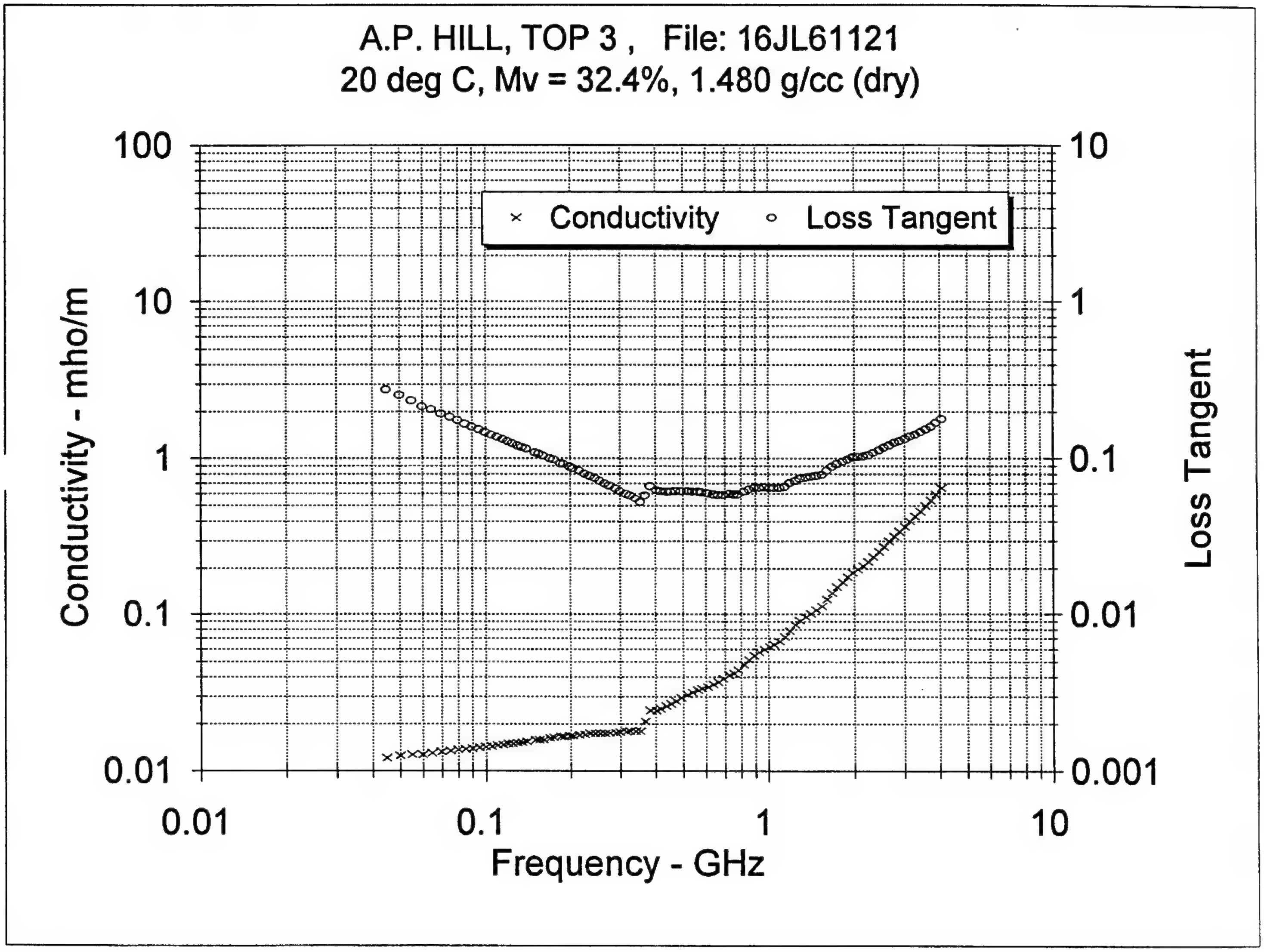
A.P. HILL, TOP 3 , File: 16JL61121
20 deg C, Mv = 32.4%, 1.480 g/cc (dry)

0.045	17.6445	4.8927	0.0122	0.2773	4.7232	0.2359
0.05	17.6005	4.5016	0.0125	0.2558	4.8412	0.2365
0.055	17.5561	4.1513	0.0127	0.2365	4.9227	0.237
0.06	17.5112	3.7916	0.0127	0.2165	4.9166	0.2376
0.065	17.4738	3.6187	0.0131	0.2071	5.0912	0.238
0.07	17.4501	3.4037	0.0132	0.1951	5.1636	0.2383
0.075	17.4354	3.2313	0.0135	0.1853	5.2569	0.2385
0.08	17.3945	3.0737	0.0137	0.1767	5.3421	0.2388
0.085	17.3572	2.9168	0.0138	0.168	5.3941	0.2392
0.09	17.331	2.7868	0.0139	0.1608	5.4626	0.2394
0.095	17.3132	2.6758	0.0141	0.1546	5.5405	0.2396
0.1	17.2805	2.5664	0.0143	0.1485	5.6003	0.2399
0.105	17.2512	2.4672	0.0144	0.143	5.6587	0.2402
0.11	17.2448	2.3865	0.0146	0.1384	5.7363	0.2402
0.115	17.2166	2.3019	0.0147	0.1337	5.79	0.2405
0.12	17.2013	2.2332	0.0149	0.1298	5.865	0.2406
0.125	17.1788	2.1584	0.015	0.1256	5.9092	0.2408
0.13	17.1581	2.0932	0.0151	0.122	5.9642	0.241
0.135	17.1454	2.0315	0.0152	0.1185	6.0138	0.2411
0.14	17.1293	1.9821	0.0154	0.1157	6.0884	0.2412
0.15	17.1053	1.8816	0.0157	0.11	6.198	0.2414
0.155	17.0923	1.8362	0.0158	0.1074	6.2527	0.2415
0.16	17.0757	1.7921	0.0159	0.1049	6.3028	0.2417
0.17	17.0612	1.712	0.0162	0.1003	6.4008	0.2418
0.175	17.0427	1.6752	0.0163	0.0983	6.4515	0.2419
0.185	17.026	1.5993	0.0165	0.0939	6.515	0.2421
0.19	17.0197	1.57	0.0166	0.0922	6.57	0.2421
0.2	17.0065	1.5086	0.0168	0.0887	6.6485	0.2423
0.205	16.9991	1.4782	0.0168	0.087	6.6787	0.2423
0.215	16.9907	1.421	0.017	0.0836	6.7357	0.2424
0.225	16.9846	1.3683	0.0171	0.0806	6.7895	0.2424
0.235	16.9824	1.3209	0.0173	0.0778	6.8462	0.2425
0.245	16.9789	1.2695	0.0173	0.0748	6.8608	0.2425
0.255	16.977	1.2213	0.0173	0.0719	6.8706	0.2425
0.265	16.9867	1.1821	0.0174	0.0696	6.9091	0.2425
0.275	16.989	1.1424	0.0175	0.0672	6.929	0.2425
0.29	17.0028	1.0912	0.0176	0.0642	6.977	0.2424
0.3	17.0129	1.059	0.0177	0.0622	7.0024	0.2423
0.315	17.0291	1.0174	0.0178	0.0597	7.0609	0.2422
0.325	17.0464	0.9898	0.0179	0.0581	7.0839	0.2421
0.34	17.0756	0.9521	0.018	0.0558	7.1226	0.2419
0.355	17.1351	0.908	0.0179	0.053	7.0806	0.2415
0.37	17.3058	1.0037	0.0207	0.058	8.1165	0.2403
0.385	17.1483	1.1402	0.0244	0.0665	9.6372	0.2414
0.405	17.0781	1.0796	0.0243	0.0632	9.6193	0.2419
0.42	17.0712	1.0617	0.0248	0.0622	9.8123	0.2419
0.44	17.0617	1.0572	0.0259	0.062	10.2382	0.242
0.455	17.0543	1.0575	0.0268	0.062	10.5923	0.242
0.475	17.0404	1.0602	0.028	0.0622	11.0908	0.2421

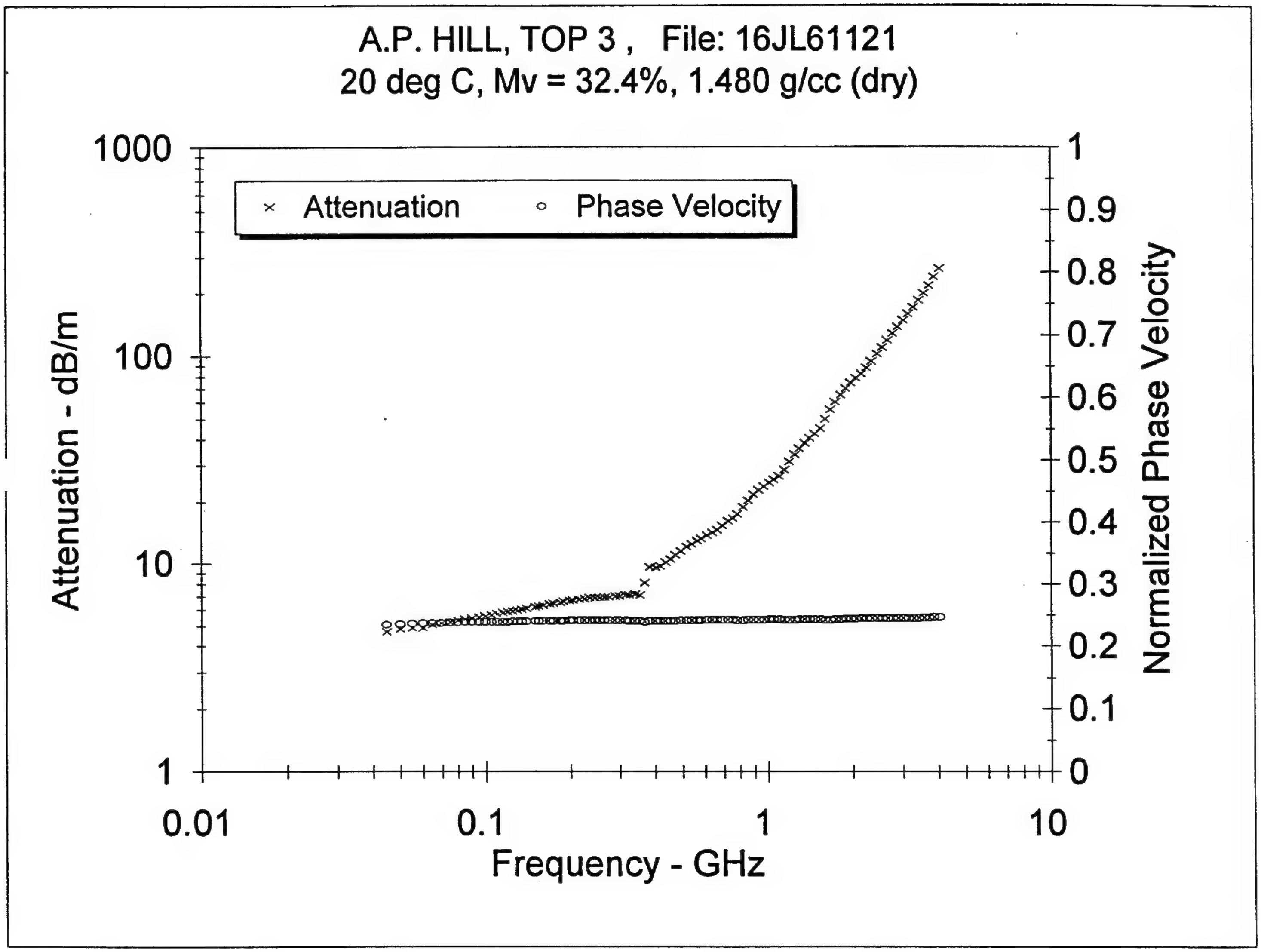
0.495	17.0218	1.0622	0.0292	0.0624	11.5863	0.2423
0.52	16.9992	1.0584	0.0306	0.0623	12.1362	0.2424
0.54	16.9835	1.0523	0.0316	0.062	12.5362	0.2425
0.565	16.9628	1.0407	0.0327	0.0614	12.9796	0.2427
0.585	16.9506	1.0302	0.0335	0.0608	13.3082	0.2428
0.61	16.9382	1.0174	0.0345	0.0601	13.7094	0.2429
0.64	16.9323	1.0034	0.0357	0.0593	14.1886	0.2429
0.665	16.9322	0.9971	0.0369	0.0589	14.6502	0.2429
0.695	16.9348	0.9994	0.0386	0.059	15.3451	0.2429
0.725	16.9297	1.0124	0.0408	0.0598	16.2187	0.2429
0.755	16.9168	0.999	0.0419	0.0591	16.6723	0.243
0.785	16.9483	1.0072	0.044	0.0594	17.4618	0.2428
0.82	16.9454	1.0448	0.0476	0.0617	18.9213	0.2428
0.855	16.9236	1.0733	0.051	0.0634	20.2797	0.243
0.895	16.8906	1.0943	0.0545	0.0648	21.6654	0.2432
0.93	16.8637	1.1028	0.057	0.0654	22.7054	0.2434
0.97	16.8369	1.1038	0.0595	0.0656	23.7206	0.2436
1.015	16.8207	1.0998	0.0621	0.0654	24.7447	0.2437
1.055	16.8171	1.096	0.0643	0.0652	25.6333	0.2437
1.1	16.8216	1.0924	0.0668	0.0649	26.6359	0.2437
1.15	16.863	1.1204	0.0716	0.0664	28.5244	0.2434
1.195	16.8559	1.1771	0.0782	0.0698	31.1442	0.2434
1.25	16.833	1.2241	0.0851	0.0727	33.901	0.2436
1.3	16.8081	1.2532	0.0906	0.0746	36.1189	0.2437
1.36	16.7817	1.2752	0.0964	0.076	38.4798	0.2439
1.415	16.7686	1.2896	0.1015	0.0769	40.502	0.244
1.475	16.7683	1.2979	0.1065	0.0774	42.4913	0.244
1.54	16.8161	1.3238	0.1134	0.0787	45.1855	0.2437
1.605	16.8308	1.4069	0.1256	0.0836	50.0223	0.2435
1.675	16.812	1.4885	0.1386	0.0885	55.2567	0.2436
1.745	16.7777	1.5526	0.1507	0.0925	60.1002	0.2439
1.82	16.7382	1.6039	0.1623	0.0958	64.8267	0.2441
1.9	16.698	1.6567	0.175	0.0992	69.9792	0.2444
1.98	16.6424	1.6898	0.186	0.1015	74.504	0.2448
2.065	16.6019	1.7014	0.1954	0.1025	78.3281	0.2451
2.155	16.5833	1.7154	0.2056	0.1034	82.4597	0.2452
2.25	16.5823	1.7439	0.2182	0.1052	87.5229	0.2452
2.345	16.5851	1.8044	0.2353	0.1088	94.3677	0.2452
2.445	16.5615	1.8748	0.2549	0.1132	102.2903	0.2453
2.55	16.5372	1.9402	0.2751	0.1173	110.4747	0.2455
2.66	16.5175	2.0067	0.2968	0.1215	119.2447	0.2456
2.775	16.5002	2.0773	0.3205	0.1259	128.8276	0.2457
2.89	16.4856	2.142	0.3442	0.1299	138.3885	0.2458
3.015	16.4754	2.2088	0.3703	0.1341	148.904	0.2458
3.145	16.4571	2.2799	0.3987	0.1385	160.3878	0.2459
3.28	16.4259	2.3512	0.4288	0.1431	172.6369	0.2461
3.42	16.3819	2.4243	0.461	0.148	185.8244	0.2464
3.57	16.326	2.5183	0.4999	0.1543	201.7904	0.2468
3.72	16.2681	2.6223	0.5424	0.1612	219.2828	0.2471
3.88	16.2194	2.754	0.5942	0.1698	240.4744	0.2474
4.045	16.184	2.9014	0.6526	0.1793	264.3022	0.2476



A.P. HILL, TOP 3 ,   File: 16JL61121
20 deg C, Mv = 32.4%, 1.480 g/cc (dry)
100
10
1
0.1
Relative Dielectric Constant
0.01
0.1
1
10
Frequency - GHz
Real
Imaginary

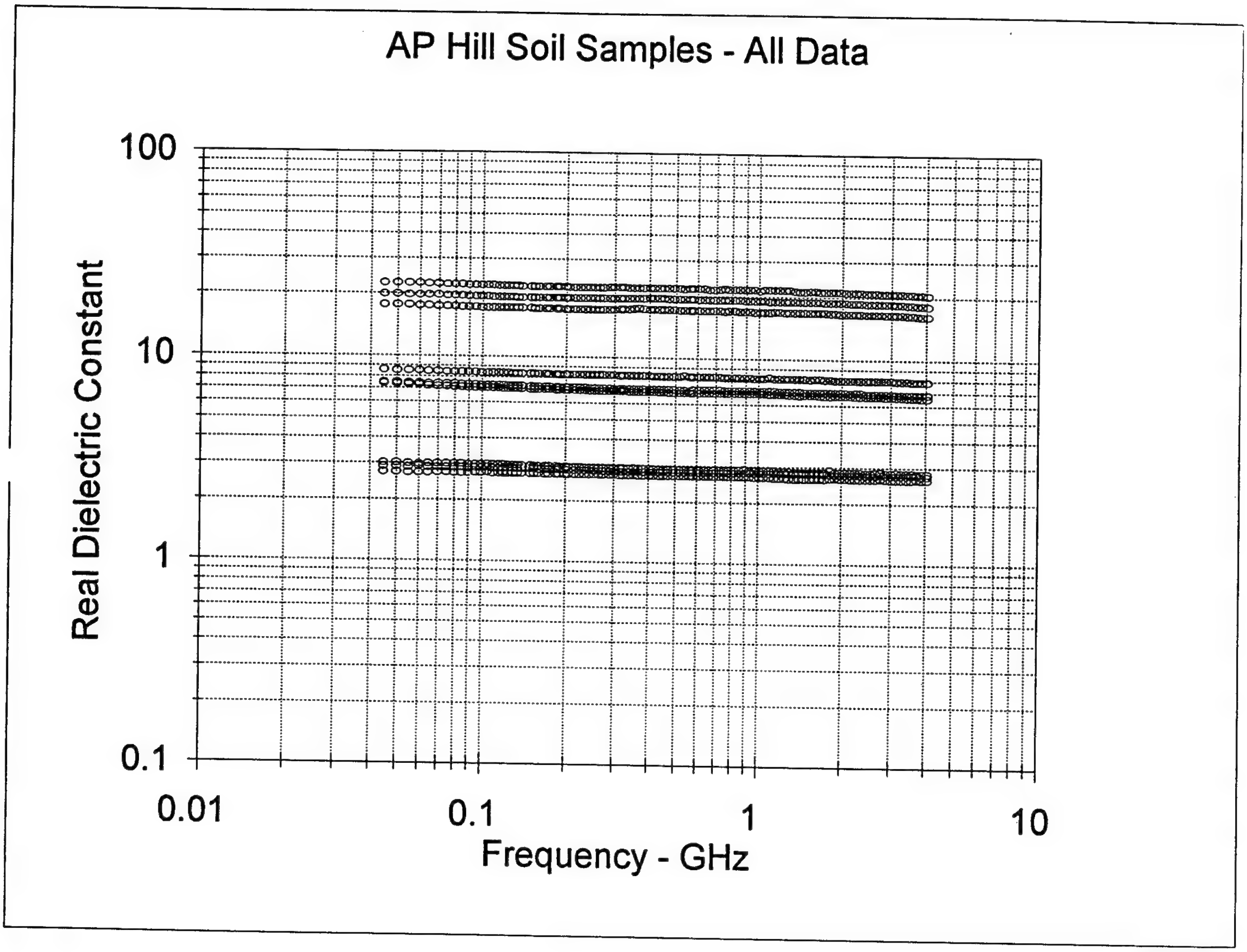


A.P. HILL, TOP 3 , File: 16JL61121
20 deg C, Mv = 32.4%, 1.480 g/cc (dry)
Conductivity
Loss Tangent
100
10
1
0.1
0.01
Conductivity - mho/m
10
1
0.1
0.01
0.001
Loss Tangent
0.01
0.1
1
10
Frequency - GHz

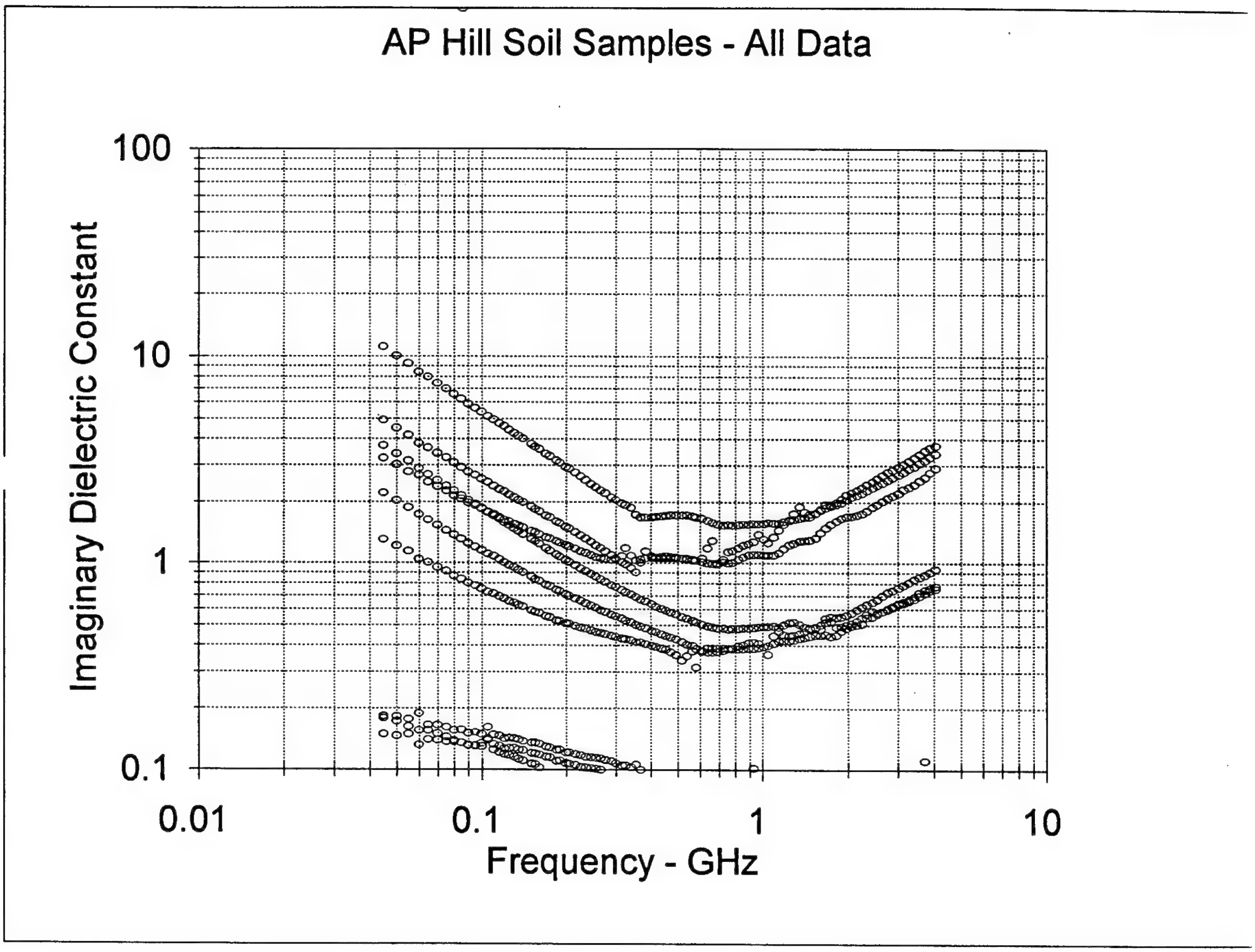


A.P. HILL, TOP 3 , File: 16JL61121
20 deg C, Mv = 32.4%, 1.480 g/cc (dry)
Attenuation
Phase Velocity
Attenuation - dB/m
Normalized Phase Velocity
Frequency - GHz
1000
100
10
1
0.01
0.1
1
10
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0

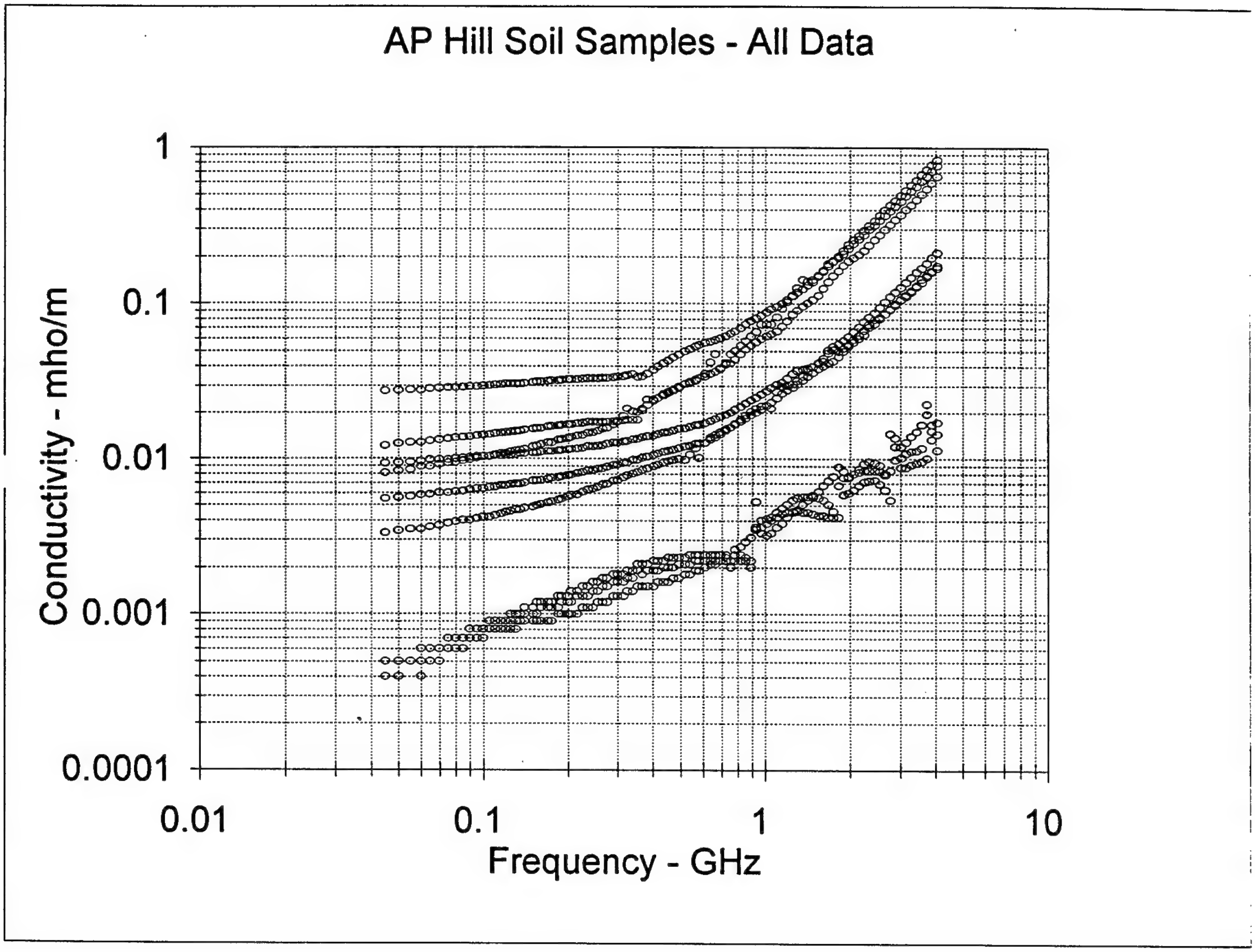
Fort A.P. Hill
Collective Sample Results



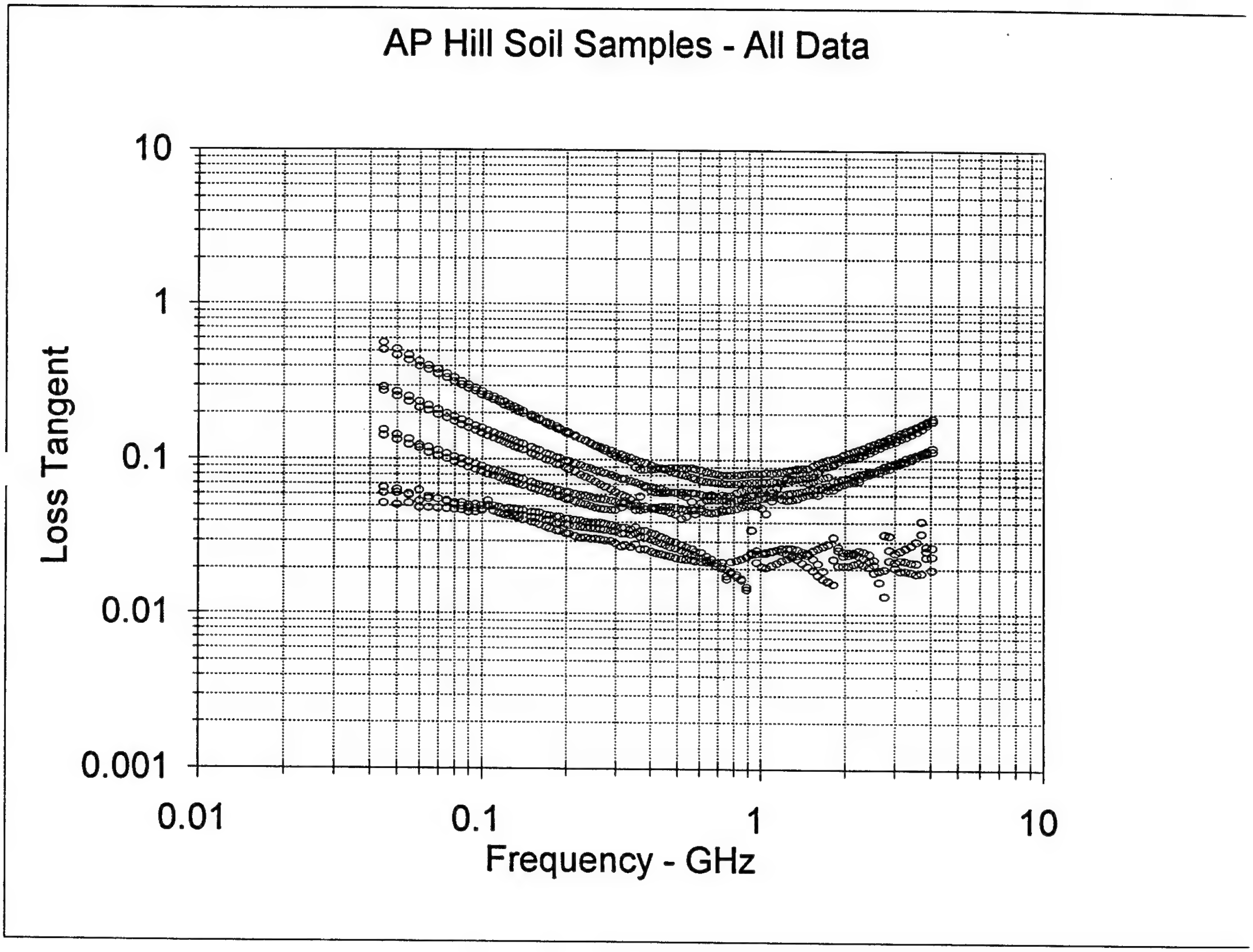
AP Hill Soil Samples - All Data
100
10
1
0.1
Real Dielectric Constant
0.01
0.1
1
10
Frequency - GHz



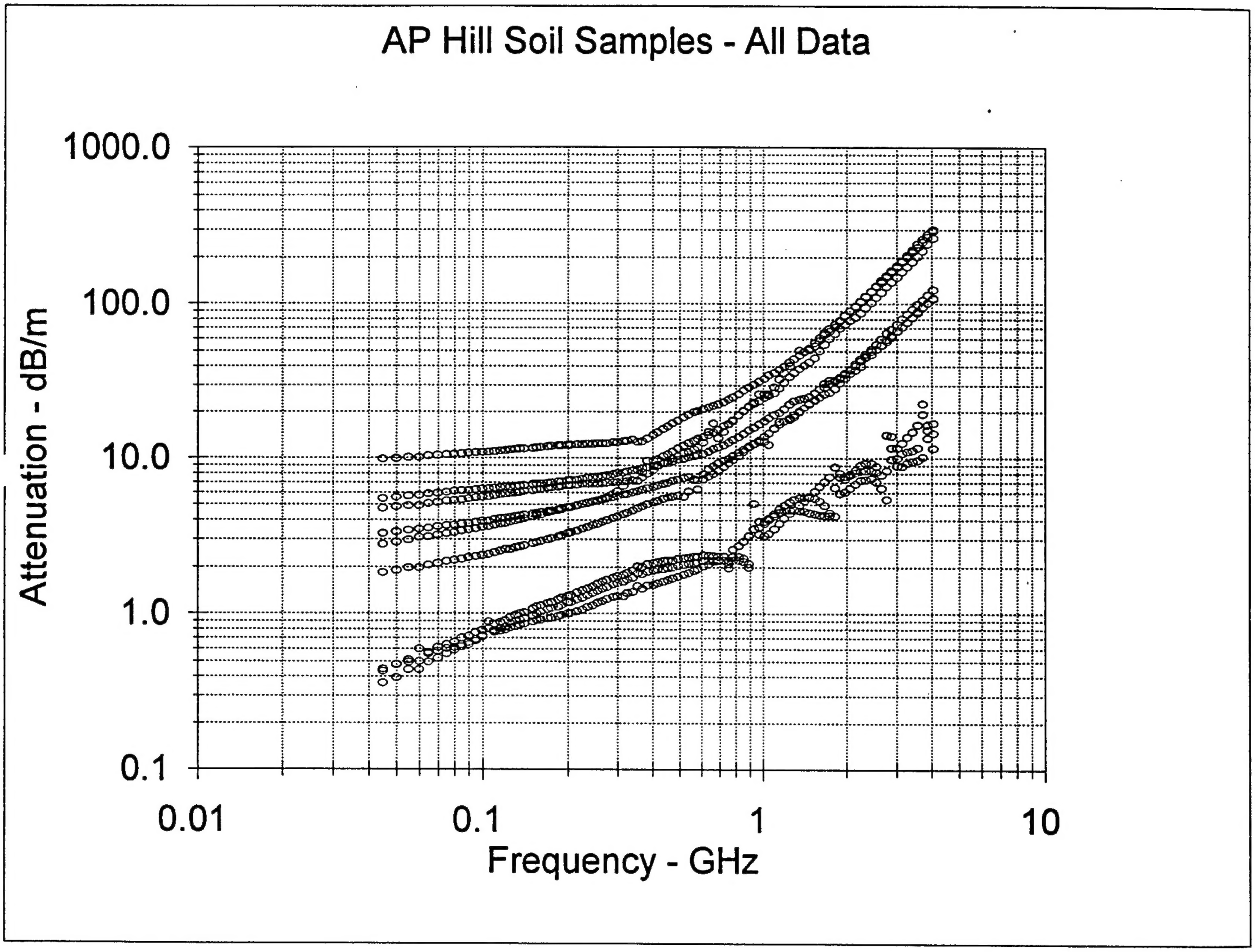
AP Hill Soil Samples - All Data
100
10
1
0.1
Imaginary Dielectric Constant
0.01
0.1
1
10
Frequency - GHz

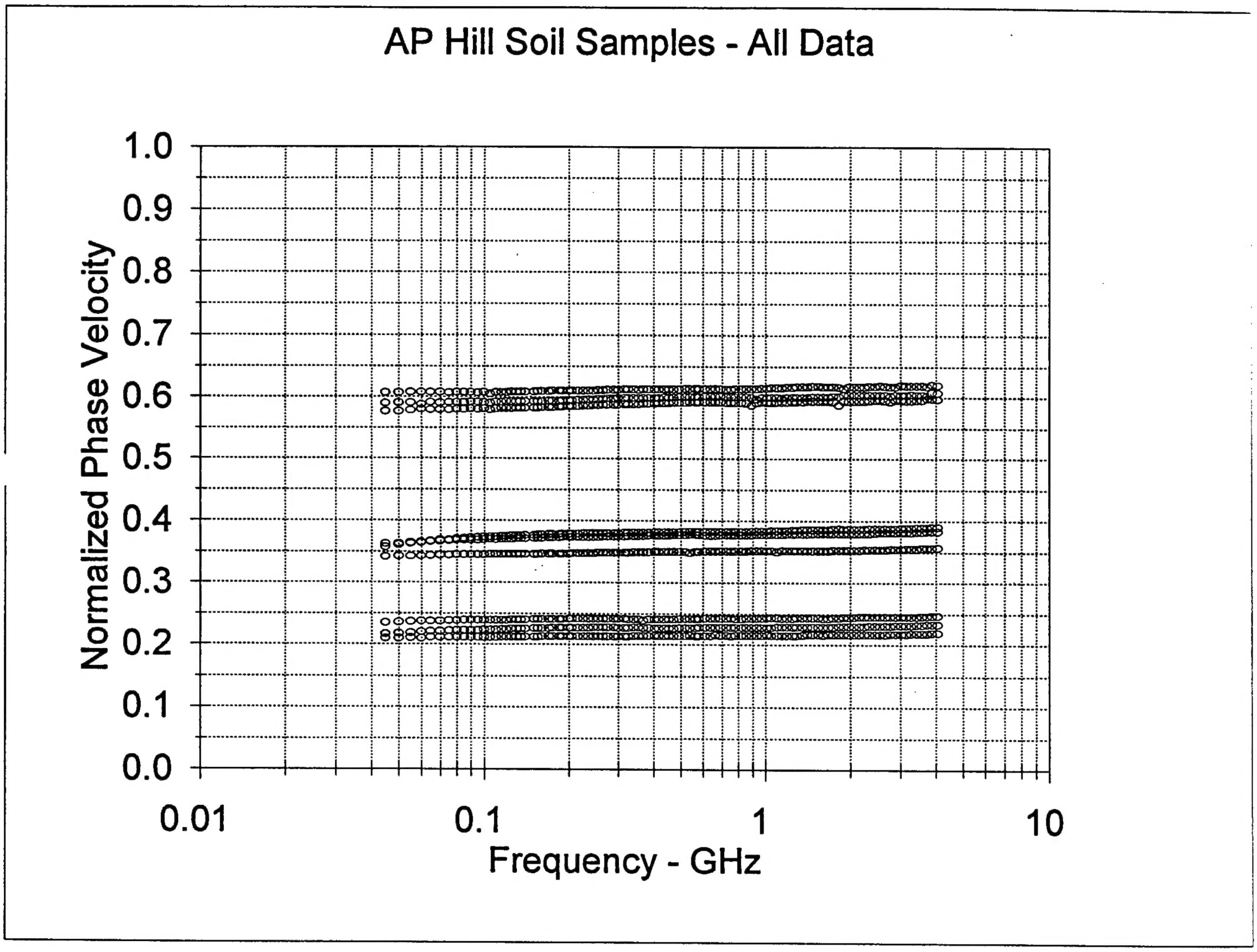


AP Hill Soil Samples - All Data
Conductivity - mho/m
1
0.1
0.01
0.001
0.0001
0.01
0.1
1
10
Frequency - GHz



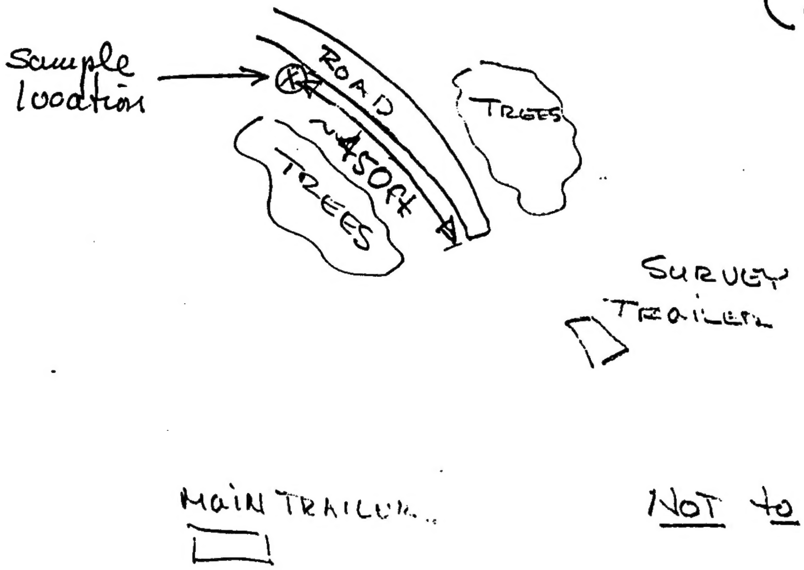
AP Hill Soil Samples - All Data
Loss Tangent
10
1
0.1
0.01
0.001
0.01
0.1
1
10
Frequency - GHz


AP Hill Soil Samples - All Data
Attenuation - dB/m
1000.0
100.0
10.0
1.0
0.1
0.01
0.1
1
10
Frequency - GHz


AP Hill Soil Samples - All Data
Normalized Phase Velocity
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.01
0.1
1
10
Frequency - GHz

Ft. A.P. Hill Soil Samples
Collected 21 MAR 96

① Sample - OFF Road
Collected in off Road Area (Material collected in top 4")



Not to Scale

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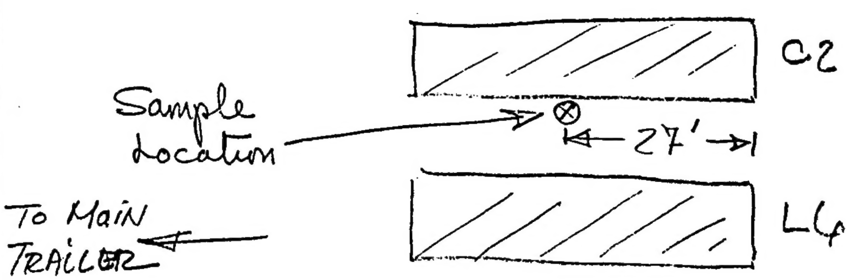
② Sample - top 3"
Collected by hand held Area

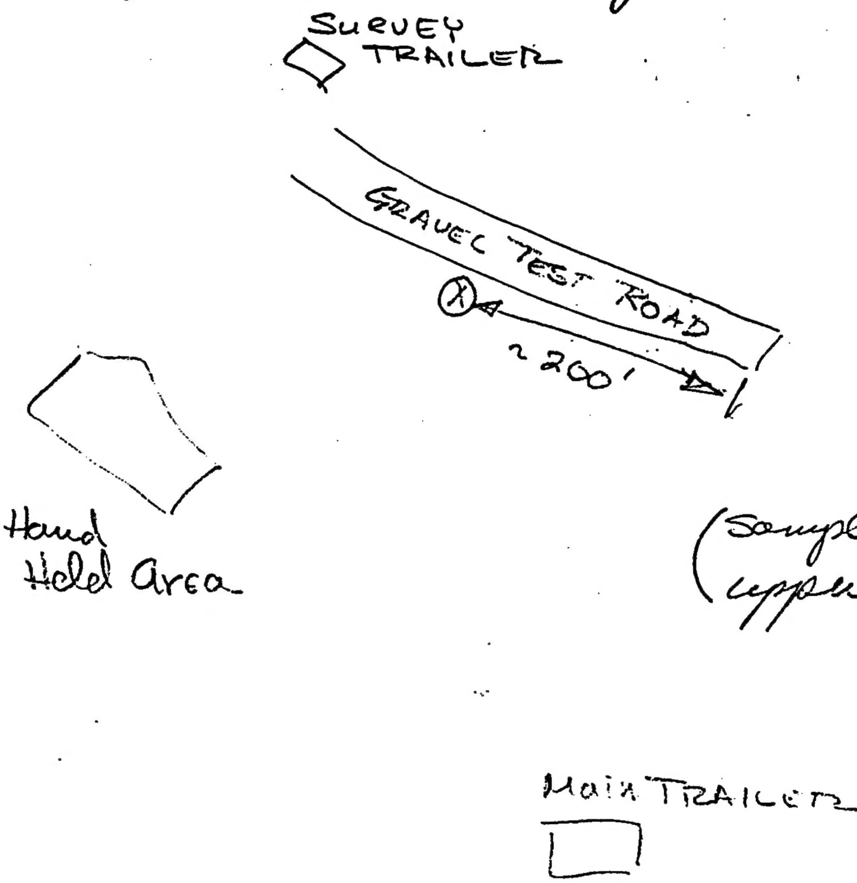


NOT TO SCALE

(Sample collected in top 3")

③ Sample - Dart Road

Sample collected by Vehicle Road



(Sample collected in
upper 4")

NOT to SCALE